Popular Astronomy.

Vol. XXI, No. 4. APRIL, 1913. Whole No. 204

THE SPECTROSCOPIC DETERMINATION OF STELLAR VELOCITIES CONSIDERED PRACTICALLY. *

EDWIN B. FROST. †

The spectroscopic procedure of finding the component in the line of sight of a star's velocity in space was practically inaugurated by the late Sir William Huggins in 1867. Christian Doppler had advanced in 1843 the view that a velocity of approach involved a displacement of the star's radiations toward the violet, and he drew the mistaken inference that in the case of a double star the bluish component star must be approaching while the reddish star must be receding. He was unaware of the extension of the spectrum in both directions beyond the range of vision, whereby any such displacement as he imagined would introduce new infra-red or ultra-violet rays into the star's light so that the color would remain unchanged. Furthermore, such effects as he pictured would have involved stellar velocities of almost the order of the speed of light, vastly greater than are met with in fact. To the ingenious Fizeau we are indebted for the definite formulation in 1848 of the principle that the lines in the spectrum will be displaced if the star and observer are approaching toward or receding from each other. Fizeau recognized the necessary minuteness of the displacement to be expected, but was hopeful that it might be detected. It is only just that this important principle should be known by the name of Fizeau as well as that of Doppler, and be designated as the Doppler-Fizeau principle.

* Read at the Cleveland meeting of the American Association for the Advancement of Science Dec. 31, 1912, at a joint session of Sections A and B, the Astronomical and Astrophysical Society of America, the American Physical Society and the American Mathematical Society.

† Vice President of Section A.

Although the correctness of the principle was for a time disputed by some, the enormous advantage of obtaining a linear measure of the velocity in the line of sight of the celestial bodies was recognized soon after Huggins began his observations. Particularly significant is the fact that the precision of the measurement does not depend upon the distance (as is unfortunately the case with most astronomical measures), but may be as exact for the most distant as for the nearest star, provided it gives us sufficient light.

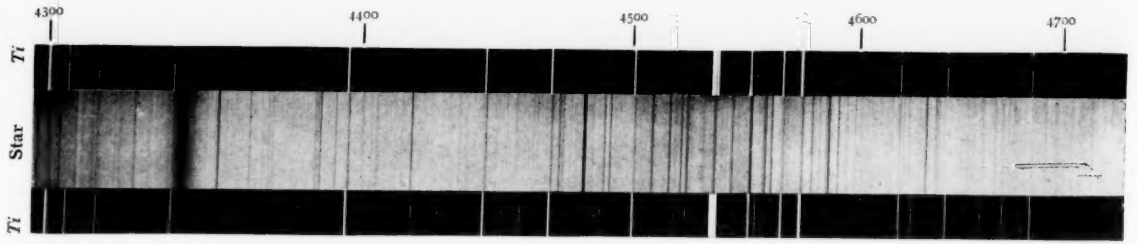
Concisely stated, the ratio of the displacement of the spectral line to its wave-length is equal to the ratio of the star's velocity to the velocity of light or

$$\frac{\text{displacement}}{\text{wave-length}} = \frac{\text{velocity of star}}{\text{velocity of light}}.$$

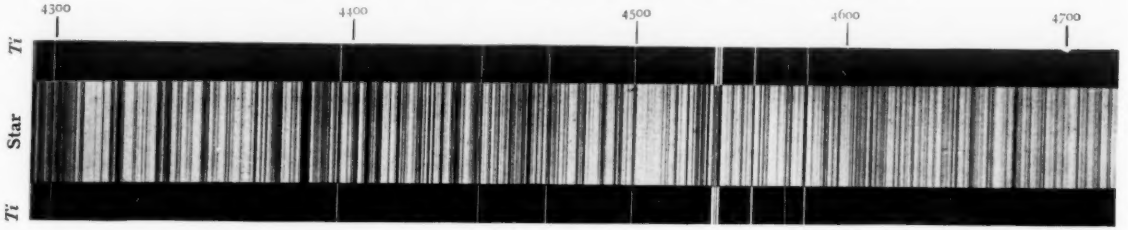
In expressing it thus we are assuming that the observer is absolutely at rest; but the term velocity of star must be construed as the velocity with which the star and observer are approaching or receding from each other. As the observer is situated upon an earth rotating with a speed of one-half km per second at the equator, and revolving around the sun with a speed of 30 kilometers (about 19 miles) per second, it is evidently necessary to make a correction for these terrestrial motions. We should then get the velocity of the star with respect to our sun.

We know that the sun is moving with a speed of about 20 km per second toward a point in the sky near R. A. 270°, north declination 30°, or between the constellations Hercules and Lyra. Hence we must correct the observed velocity for the effect on each star of this velocity of the sun, and we obtain the star's velocity with respect to the center of gravity of the large number of stars upon which rests the determination of the sun's speed and direction. If this large number of reference stars is subject to some systematic drift, as seems to be probable, then another correction would have to be applied before we could obtain the absolute velocity of the star. It is hopeless to try to find any reference point in the universe which is absolutely at rest, even if there be such a thing as absolute velocity. In common practice we denote by the words radial velocity of a star the component of its velocity in the line of sight referred to our sun.

PLATE IX



η Leonis. Star and earth were separating at speed of 18 miles per second.



α Boötis (*Arcturus*). Star and earth were approaching at speed of 11 miles per second.

Stellar Spectra Photographed with the Bruce Spectrograph (Frost and Adams)

The white lines are due to titanium vaporized by an electric spark in front of the spectrograph. They furnish reference points on every plate. The dark lines on a light background are in the spectrum of the star. From the lack of perfect coincidence of the titanium lines in spark and star, the velocity of the star may be inferred, after positions of lines have been measured to one twenty-five-thousandth of an inch. After correcting for the earth's velocity (in its orbit around the sun), the above stars are found to have speeds of 2 miles per second (recession) and 3 miles per second (approach) respectively.

It is natural that a demonstration of the validity of the Doppler-Fizeau principle should be desired; and it has been furnished in various ways. One of the earliest confirmations was given independently by Young and by Vogel, who projected successively the eastern and western limbs of the sun upon the slit of the spectroscope and measured the displacement of the lines due to the sun's axial rotation. The results agreed with the velocity inferred from the rotation derived from the motion of the sun-spots. More satisfactory is the proof of the principle derived from determinations of the radial velocities of the planets, which are found to agree closely with the values calculated from the known orbital motion of the planet. This method is regularly employed by observers to check the adjustment of their spectrographs.

If further proof of the correctness of the principle were necessary, it is afforded by the precision with which the correction for the earth's orbital velocity justifies itself in the case of stars having uniform radial velocities. The following illustration shows how this correction to the discordant velocities at different dates brings them into close agreement:

β Geminorum.

Date	1902 Dec. 31	1903 Feb. 5	1903 Apr. 8
Observed Velocity	−2.90 km	+15.86 km	+33.12 km
Correction for earth's velocity	+6.20	−12.37	−29.62
Radial velocity of star	+3.3	+ 3.5	+ 3.5 km

This is illustrated on a larger scale by the accuracy with which the distance of the sun can be obtained from observations of a star. It is obvious that if we can thus measure the speed per second of the earth's orbital velocity and know the number of seconds in the year, we can readily derive the semi-axis of the orbit or the mean distance of the sun. Thus from eighteen spectrograms of *Arcturus* Küstner obtained a much more reliable measure of the sun's distance than was yielded by all the laborious observations of the transit of *Venus*, for which many astronomers made long voyages, and for the reduction of which several years of calculating were required. A more elaborate spectrographic determination of the sun's distance was more recently made by Halm at the Cape of Good Hope with excellent results. A rather careful examination of his paper leads me to think that a still more precise

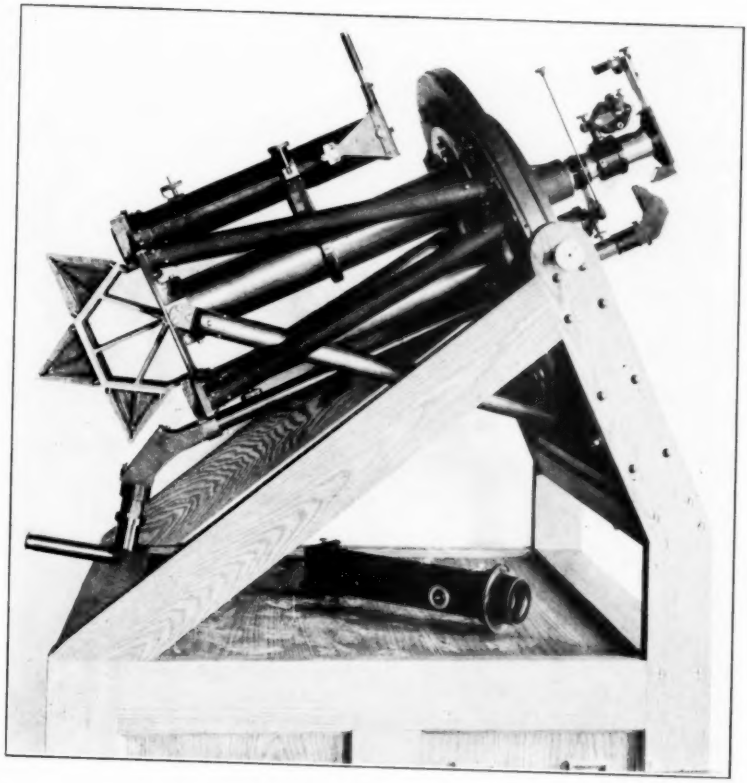
value can be obtained in this way. But in any case no better astronomical confirmation of the Doppler-Fizeau principle is needed, at least in so far as the motion of the observer is concerned.

Laboratory proofs of the principle, though very difficult, have been successfully made in Russia, first by Belopolsky at Pulkowa. He photographed the solar spectrum after the beam had suffered multiple reflections from a set of rapidly revolving mirrors. He regarded the results as provisory, but they were in very fair agreement with the displacements calculated from the instrumental conditions. A few years later (1907) Galitzin and Wilip, employing the mechanical parts of Belopolsky's apparatus and a powerful echelon spectroscope with a source of homogeneous radiation, obtained results which may be regarded as fully establishing the principle experimentally.

We must now consider briefly the instruments with which radial velocities may be determined advantageously. It is essential that a comparison spectrum be provided, which, with an exception noted later, requires a slit-spectrograph. Its optical parts are three: collimating lens (to render the rays from the slit parallel), prisms or grating, and camera lens. The sizes of these parts are determined by the angular aperture of the equatorial and by the limitations of the size in which prisms can be obtained of uniform homogeneity. At present it is not feasible to use a beam from the collimator of more than 50mm (2 inches) diameter, 40 mm is probably better than 50 mm. From one to four prisms may be employed in the train, according to the dispersion needed. The most stable construction brings the camera tube parallel to the collimator after a deviation of just 180°, usually with three prisms. Progress is being made in the manufacture of gratings which will concentrate their light to a considerable extent in a single order, so that their use is becoming more feasible, but in general they are too wasteful of light for use on faint objects. The comparison spectrum is produced from a spark (or arc) between metallic terminals, as iron, titanium, or similar metal, projected upon the parts of the slit on either side of the small portion of the center reserved for the star's image. The greatest of care must be taken that the rays from the source of comparison traverse the lenses and prisms in precisely the same manner as does the star's light.

The early visual observations by Huggins, Vogel and later by the Greenwich observers, were of extraordinary difficulty; it was in fact

PLATE X



BRUCE SPECTROGRAPH ON CARRIAGE.

generally impossible to conclude whether the star was approaching or receding. It was not until the photographic procedure was worked out by Vogel and Scheiner in 1888-9 that reliable results could be obtained, with the new type of instrument of Vogel's design, which he named spectrograph. Aside from the value of an automatic record, the photographic plate had the advantage of being susceptible of repeated measurement by one or many observers, under a suitable microscope-measuring machine, with proper regard for the observer's comfort and psychological attitude. The velocities of 52 of the brightest northern stars resulted from the Potsdam campaign and they seem to have generally been accurate within about one of the units employed, the German geographical mile or 7.4 km. Vogel also perceived the value of a comparison spectrum having many lines (hydrogen had usually been employed) and used the spark spectrum of iron for the star *Sirius*.

The next great advance was made at the Lick Observatory by Campbell, who designed the Mills spectrograph (1895), and worked out a method of measuring and reducing spectrograms so as to utilize all the good stellar lines, referring them to numerous adjacent comparison lines of the spark spectrum of iron. A comprehensive program was laid out for obtaining the radial velocities of all the brighter stars having sharp lines, and the branch Mills Observatory was established in Chile to include the southern stars. Some of the results of this campaign of over fifteen years are now appearing in a series of masterly papers by Campbell, including new determinations of the sun's motion, and studies of the progression of intrinsic velocity according to spectral type, and the publication of results for the individual stars (toward 1000) may be soon expected. The other observatories at which regular spectrographic work has been carried on in recent years are, roughly in order of time, Pulkowa, Potsdam, Cambridge (England), Paris, Yerkes, Lowell, Ottawa, Cape of Good Hope, Bonn, Allegheny, Mt. Wilson, Michigan. There is ample work for all to do, and it is constantly enlarging our knowledge of the sidereal universe, already greatly enriched by the contributions of the spectroscope.

We must mention two other forms of apparatus with which radial velocities may be determined more or less satisfactorily. The first is the objective-prism, historically the original form used for examining stellar spectra, and brought to great service by E. C. Pickering in apply-

ing it with photography to the spectroscopic study of the entire sky. Numerous attempts have been made to utilize the objective-prism for radial velocities, dealing with many stars on a single plate. But the quantities sought are so small that the errors due to distortion of field and to change of temperature of the exposed prism, are of the order to mask the displacements sought. The most promising plan has been lately put in practice by interposing an absorbing film which should produce comparison lines across each spectrum. The long-felt difficulty of finding a suitable absorbing medium has been alleviated by Wood's use of neodymium. If this yielded numerous comparison lines instead of a single one, it would be of much promise: perhaps this is only a detail which may soon be perfected; the mechanical and optical difficulties can doubtless be overcome, although it is hard to see how the instrument could compete in accuracy with even the single-prism slit spectrographs. But it may become of great utility in reconnaissance work, in the detection of large velocities on plates containing many spectra.

Experiments by S.A. Mitchell in 1899 showed that for very bright stars a large concave grating used directly (without intervening telescope) can measure absolute wave-lengths tolerably, and thus allow the radial velocity to be inferred with some degree of accuracy.

The determination of the radial velocities of stars with a modern spectrograph appears so simple in theory and practice that the general reader may easily overlook the excessive precision required in the construction of apparatus, in its operation, and in the measurement and reduction of the spectrograms. I therefore wish now to discuss some of the difficulties and defects of present methods, which may suggest where improvement may be expected.

The difficulties are of several kinds, which may be classified as follows: (a) instrumental, including those mechanical and those optical; (b) physical, due to defective knowledge of wave-lengths of light-rays; (c) stellar, due to conditions in stellar atmospheres and not yet satisfactorily reproduced in the laboratory; (d) subjective difficulties, due to the psychological element involved in the perception and measurement of very faint and vague lines on the photographic plates.

(a) To understand the refinement necessary in the mechanical construction of the spectrograph, we must consider the size of the quantities involved. Taking for example the three-prism Bruce spectrograph of

PLATE XI

Objective Prism Spectra

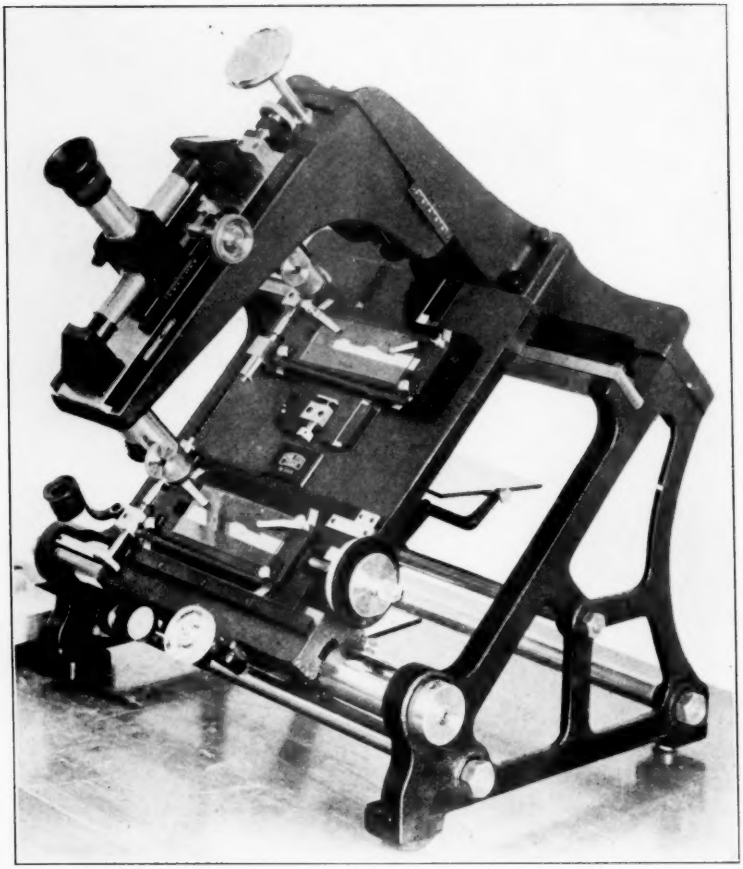
the Yerkes Observatory, one of the most powerful of those that have been in regular operation, we find that a displacement corresponding to a velocity of one kilometer per second is represented on the spectrogram by a distance of about 1/700 millimeter, or about six hundred-thousandths of an inch. Now we like to think that our measures of the speed of the brighter stars having numerous sharp lines are reliable to the nearest kilometer; (there has been talk, I think a bit premature, of significance in the tenth of the kilometer). This (the kilometer) means that there may be no flexure of the mechanical parts of the apparatus or slipping of lenses or differential changes of any of the parts which shall cause a displacement on the plate of the amount just mentioned between the position of the lines of the stellar spectrum and those of the comparison spectrum. If uniformly progressive during the exposure, however, a change of that amount, provided that it affects equally the stellar and comparison spectrum, will not vitiate the radial velocity by more than a fraction of the kilometer, but it will impair the definition and is likely to produce different effects of widening on the stellar and comparison lines. When we recall that the spectrograph is attached to a telescope that points toward all parts of the sky, so that the position of the mechanical parts and of the prisms and lenses is constantly changing with respect to the vertical, it is evident that an exceedingly rigid construction is necessary. It is a fact that many spectrographs exhibit an "hour angle error," or relative error with change of hour angle.

Changes of temperature may also produce disastrous effects upon both the mechanical and optical parts. Observatory domes are notoriously subject to changes of temperature as the night progresses. If different metals are used in certain parts of the spectrograph, the differential contraction may produce spurious displacements; but more dangerous are the effects upon the deviation and dispersion of the prisms. For instance, if a comparison spectrum is impressed on a plate in the Bruce spectrograph when at a low temperature, and this is repeated some hours later when the temperature has risen considerably (every contact with the camera having been avoided by the observer), the comparison lines will be widely double, in fact corresponding to a spurious velocity of about twenty kilometers for 1° C. In practice the comparison spectrum is meant to be impressed often enough during the exposure of the star so that the effects will be the same on each. But

no one would try to derive a radial velocity from a plate on which the comparison lines showed the least evidence of doubling. It is obvious, however, that automatic thermostats are essential to protect the prisms from changes of temperature, and such precautions are always taken, The definition of the lines also suffers from any lack of thermal equilibrium of the glass, introducing an inaccuracy difficult to control. On a warm day the spectrograph will necessarily rise in temperature, but the heat will only reach the interior of large prisms after some hours, so that with the cooling at night-fall, the prisms are likely to be in a state of thermal strain despite the thermostat (which ordinarily prevents only a fall in temperature, by means of an electric heating coil). A remedy would be to keep the spectrograph in a cool chamber, where the temperature should not rise above that likely to be found at the beginning of a night's operations. Changes of temperature also sometimes produce a strain in the balsam of cemented lenses, if their aperture is greater than one inch, causing distortion of the surfaces of the glass and a most disagreeable impairment of the definition of the spectrum.

(b) We pass to some of the difficulties of a physical kind: first, the inaccuracies of the wave-lengths in the tables upon which we have to depend. We know that Rowland's great map and tables are absolutely too large by nearly 0.2 of the unit, the ten-millionth of a millimeter, now called the Angström. This error, however, affects equally the comparison and stellar lines, and has no effect on velocities; but the relative and accidental errors of Rowland's tables, which are known to reach a value of 0.02 or even 0.03, may affect the result with their full value, equivalent to from 1.5 to 2.0 km per second. If the identical lines are used in comparison and stellar spectrum, this element of error is avoided; but the gain from the use of the best lines in the spectrum of the star, even if they are not in the comparison, is too great to be neglected. But these uncertainties of wave-length are in the way of elimination by the important undertaking of the International Solar Union in the establishment of new tables of wave-lengths based upon the interferometer measures of Michelson and Benoit on the red cadmium line, and extended to many iron lines by the interferometer method by Fabry and Buisson at Marseille, by Pfund at Johns Hopkins and by Eversheim at Bonn. On these are founded measures with the grating at Bonn by Professor Kayser and his students, and elsewhere, so that

PLATE XII



THE HARTMANN SPECTRO-COMPARATOR.

we may soon expect to know the wave-lengths of a sufficient number of lines in the arc spectra of the elements with a relative accuracy of not more than 0.003 Angströms, (corresponding to only 0.2 km per second).

But we have also the uncertainty due to the possibility of small differences in the wave-length of the same line in the arc and in the spark spectrum. This matter has been persistently studied by Kent, who concludes that the differences found (of the order of 0.02 to 0.03 Angströms, or about the same as the relative errors in parts of Rowland's table), are due to satellites which develop on the sides of spark lines as the discharge becomes more highly disruptive with variation of the inductance. The arc spectrum may be easily used for the comparison spectrum (as has been done by Hartmann and others), especially for iron, but the spark has had the preference in practice heretofore.

During the past ten years it has been necessary to use for wave-lengths of the stellar spectrum those taken from Rowland's table for the solar spectrum; if the lines occur in the star, this involves a small error due to the way in which Rowland established his standards. For stars of the first type the laboratory values from vacuum tubes are used for helium lines, if present, and from the spark for other metallic lines. We shall presently see that stellar conditions alter these laboratory wave-lengths very appreciably when the effect is expressed in kilometers.

I next mention a serious difficulty which might be also classed under those of a subjective nature. When the spectrum of the sun is photographed with higher and higher dispersion, we find a steady increase in the lines which are brought into view, i. e., lines apparently single at low dispersion break up into doubles and groups with higher power. Thus the low dispersion necessary in stellar work causes groups of lines separated on Rowland's map to blend into what may appear to be single, sharp lines, for stars of the solar type. What wave-lengths shall we assign to these blends? If we may make the doubtful but rather necessary assumption that the stellar spectrum is a precise duplicate of that of the sun, we may arithmetically compound the group into a blend by multiplying each constituent line's wave-length by its intensity as given by Rowland. This somewhat dubious procedure yields tolerably good results. Or spectrograms of the sun and planets may be measured, and the wave-lengths may be adjusted by least-squares, for a system

to be regularly used in case of such stars; this may introduce systematic errors.

Again, recourse may be had with advantage to the ingenious spectro-comparator of Hartmann. This instrument, by a combination of two objectives uniting the rays in one eye-piece, brings two spectrograms into view simultaneously, in a sort of interrupted superposition. The central portion of the upper comparison line, of the stellar spectrum, and of the lower comparison line are due to the stellar spectrogram, the outer parts of these same lines are due to a standard solar spectrum on which is also impressed the regular comparison spectrum. A micrometer-screw moves one spectrogram, the other being fixed; a group of comparison lines is first aligned, the broken lines being united into complete ones; then the solar and stellar lines by groups are made to coincide; the difference in the micrometer readings measures the displacement of the stellar lines with respect to the lines of the solar standard. The procedure of aligning the groups of lines is rapidly executed, the reduction is simple, and, of most importance, does not involve a very exact knowledge of the wave-lengths in sun and star; but it assumes that the two spectra are identical, so that the method has less advantage in absolute accuracy over that first mentioned than might be inferred from the excellent accordance in the velocities from the separate groups.

(c) As we pass to spectra differing increasingly from that of the sun, our difficulty of assigning the proper wave-length increases, and it is necessary to use great care in the endeavor to select lines which are unaffected by close companions. But when all precautions are taken, certain lines apparently single stand out in disagreement with their fellows. We owe to Albrecht a valuable study of the behavior of the same lines in the spectra of stars progressively differing in type. From this it appears that corrections amounting to several kilometers may have to be applied to the velocity derived from the same line but for stars differing not widely in type.

For instance, for the line due to titanium at λ 4468.663 he found the following departures expressed in kilometers with change of type:

Type	F	F8G	G	G5K	K	K5M	M5	
	−2.1	−1.0	−0.9	+0.2	+1.3	+4.3	+4.7	km.

PLATE XIII

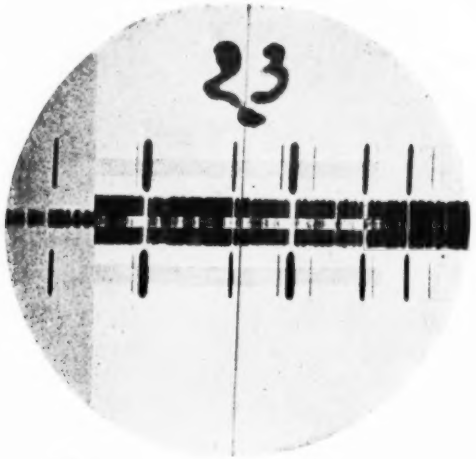


FIG. 1. Comparison Lines in Coincidence.

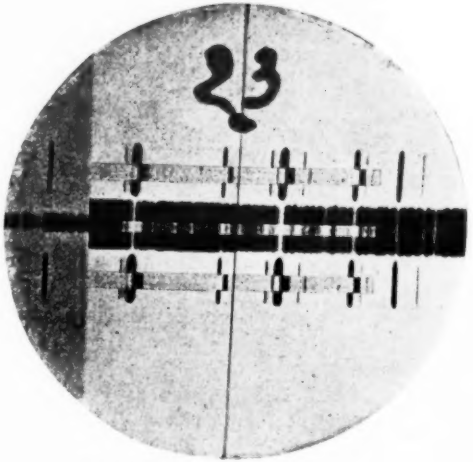


FIG. 2. Star Lines in Coincidence.

FIELD OF THE HARTMANN SPECTRO-COMPARATOR.

It seems necessary to regard these differences as due to differences in pressure in the stellar atmospheres. We know that the solar lines originate at different levels, and hence in regions of different pressure. Perot has recently determined the pressure in the solar reversing layer as 4 atmospheres. It is well known that lines of different elements and of different spectral series of the same element are differently displaced toward the red by increased pressure in the laboratory experiments. From this it will be sufficiently evident that for the greatest refinement we shall need to study each star line by line and each important line in its changes with spectral type. While this tends to postpone the day when we shall arrive at certainty with respect to tenths of the kilometer, the differences found will on the other hand give us information as to atmospheric conditions of those stars.

We might expect *a priori*, and did expect a few years ago, that these difficulties due to blending of lines would be least for stars of the first type having few lines chiefly of hydrogen, helium, silicon, calcium magnesium, etc. The wave-lengths of these lines have been well determined in the laboratory and they are generally well separated from each other. Of course most of them are apt to be ill-defined in stars of this type, so that the accuracy of the settings is much impaired. The story is particularly interesting for the helium stars. When the speed of the sun with reference to these stars was calculated from data obtained at the Yerkes Observatory, the sun appeared to be approaching the helium stars in the region of the apex with a velocity nearly 10 kilometers slower than it was receding from the opposite point of the sky. Campbell from the Lick observations independently inferred that our measures of velocity of helium stars are affected by a constant error of nearly 5 kilometers. The discrepancy could be accounted for if we had any ground for the assumption of an outward flow or expansion of the whole girdle of helium stars lying in the Milky Way. From parallax observations and from their extremely small proper motions across the line of sight, we have known for some years that the helium stars are extraordinarily remote from the sun; our measures with the spectrograph have shown that their intrinsic velocities, as a class, are very low, 6 km, not much over a third that of the solar stars. But we cannot assign any reason why these stars should tend to move away from the casual position of our sun; and the least unlikely explanation yet advanced is that the

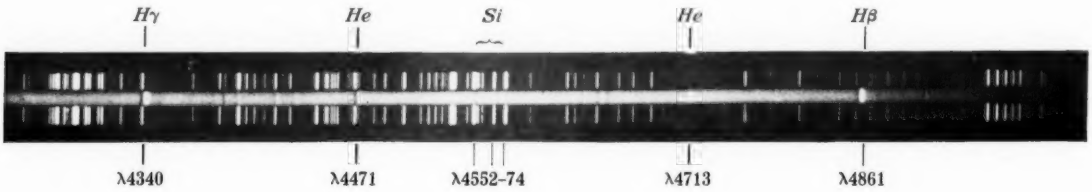
pressure in the atmospheres of these stars displaces their lines toward the red by an amount corresponding to about 5 km per second.

A variety of spectra offering special obstacles to their precise measurement are those having strong (or weak) emission lines in addition to their absorption lines, called bright-line stars. In some cases of this sort we may feel sure that an over-lapping of the spectra occurs, so that the radial velocity cannot be safely inferred from the displacements of the centers of the dark lines (which may be fairly well defined). *P Cygni*, the nova of 1600, is on illustration of this. The bright line overlies and conceals a considerable part of the dark line so that a spurious effect of large displacement toward violet is produced, differing for lines of different elements and for those of the same element. It ought to be remarked, perhaps, that this need not imply any concealment of one star by another; it is presumably merely a question of the extent of the star's atmosphere; if the gaseous atmosphere of the star is extensive enough, the quantity of light from it may exceed that from its photosphere, thus producing a reversal in the dark line. These effects are stronger for the lines of long wave-length than for those of short wave-length. There are several stars known in which the red line of hydrogen is conspicuously bright, while at the blue line, $H\beta$, emission and absorption may nearly neutralize each other, and the violet hydrogen lines are dark only. The precise measurement of such spectra for the purpose of radial velocity is exceedingly difficult and involves the psychology of the observer in a high degree.

There is no doubt that many stars have bright lines of which we are unconscious, but in which the emission affects the dark line and disturbs in an unknown degree the setting under the microscope. In fact every star would be, like our sun, a bright-line star when viewed from a position where its reversing layer could be distinguished from its photosphere.

In many stars of the first type the dark lines are so broad and vague that their measurement for radial velocity is almost hopeless. To my mind at present the best mode of dealing with them is to fit the dispersion to the star, generally with but one prism, and that of light glass and small angle; this carries with it a very low scale on the spectrogram, and corresponding decrease in the unit of precision attainable. For some spectra, for instance, a scale of 10,000 km per milli-

PLATE XIV



SPECTRUM OF P CYGNI.

With Titanium Comparison Spectrum.

meter (adequate resolution assumed) is none too low to keep down the vagueness of the lines to a point where settings can be made upon them.

(d) Some of the difficulties already mentioned involve the subjective perception of the observer, and I will refer only briefly to other points psychological, well known to those who measure spectra.

The observer is likely to make his setting under the microscope quite differently for the center of a white line on a dark background (star line on the negative) and for the center of a dark line on a bright background (comparison line on the negative). He is also likely to have a habit of setting differently on the center of a broad line from that on the center of a narrow line. The conventional practice is to measure the plate completely with violet to the left and then to repeat the process with the plate turned around so that the violet is to the right. This eliminates much of the error, which for an experienced observer might be systematically a matter of 3 or even 5 km. From a large number of measures the observer can also derive a correction to his settings on broad comparison lines, but not without danger of introducing an arbitrary element.

The best remedy would be found, I think, in the production of an unimpeachable absorption spectrum for the comparison, with numerous well distributed fine lines. But unfortunately, no method is known for producing such a spectrum.

In spite of all these hindrances to the accuracy which we wish to see attained, the results in routine practice are good, certainly better than would be expected. It is not surprising to find a range of even 10 km among 15 or 20 lines measured on the same plate, and the results for the same line on the same plate by two observers may differ by several kilometers. I am referring here to three-prism plates of solar type stars with sharp lines. The range may easily be much greater on low dispersion plates of spectra with bad lines.

One of the interesting by-products of line-of-sight observations has been the discovery of spectroscopic binary systems. This began with the detection and explanation of the periodic doubling of the lines of Mizar (*Zeta Ursae Majoris*) by Professor E. C. Pickering, and soon afterward of *Beta Aurigae*, by Miss Maury at Harvard; while almost simultaneously Vogel and Scheiner with the Potsdam spectrograph

were measuring the oscillations of *Algol* (fully establishing the long-suspected eclipse theory), and Vogel found that *Spica* (*Alpha Virginis*) was alternately approaching and receding in a period of 4 days. The discoveries, which were decidedly revolutionary, showed that our philosophy of double stars had heretofore been decidedly incomplete. Instead of widely separated bodies with periods ranging from thousands of years down to a score of years, the new-found binaries disclosed the possibility of mighty stars existing so close to each other that their outer atmospheres must in some cases be in contact and with consequently enormous velocities and very short periods (since found as short as one-fifth of a day). This was nearly 25 years ago; several more such systems were discovered at Potsdam, at Pulkowa and at Harvard in the following years; but after routine spectrographic work was taken up at the Lick Observatory and a few years thereafter at Yerkes Observatory, the numbers soon reached the hundreds. Probably not less than 700 are known or seriously suspected; there is always a long waiting list of unpublished objects of this sort at each observatory engaged in this work; the first list reported from the Mt. Wilson Observatory, where the spectrograph has recently been put into operation, contained 50.

On the basis of our Yerkes observations, I feel safe in expressing the opinion that more than one in every three of the stars of the first type (and brighter than the fifth magnitude) will prove to be spectroscopic binary. The diffuseness of the lines prevents the detection of those having small ranges of velocity, and the fainter stars have been under observation for a comparatively short time, so that many remain to be detected among the stars already on the observational programs. It remains to be seen whether this extraordinary proportion of binaries will persist when the stars of the same class fainter than fifth magnitude have been equally observed. The evidence available indicates a smaller proportion among stars of the second and third types; for them the range of variation would appear to average less and the period to be longer. The better measurability of the lines of these classes makes possible the detection of a smaller range of oscillation, so that the difference just noted may be real.

This superabundance of binaries brings with it much embarrassment in routine work, for it delays the publication of lists of velocities

because discrepancies between different plates so often turn out to be due to actual oscillations rather than merely to errors of measurement. To establish the *constancy* of radial velocity of a star, a large number of good observations are essential, extended over a long period of time; there are in fact not many stars in the sky of which we may positively assert it. Even *Arcturus* may be suspected of a petty variation, although it has been observed by more different spectrographs than almost any star; but observations reliable well within the kilometer will be required to establish it.

A difficulty arises from the fact that many binaries of early type belong to the variety having both components represented by lines. Plates may be infrequent that show the double lines well separated, and generally these will be a rather undecipherable superposition of the double lines. In publishing the data to establish the variation of such stars, it seems necessary to print the velocities inferred from the settings, but it is certain that the setting upon the center of a blend made of two unequal juxtaposed component lines does not represent the velocity of either component star, and contributes little that may be useful for determining the orbit of the system.

The great number of spectroscopic binaries already found, far beyond any *a priori* expectations, may well lead us to carefully re-examine our premises. Is it not possible that there may be some physical explanation other than the dynamical one of two or more separate bodies revolving around their mutual center of gravity?

Doublings and multiplication of spectral lines can be produced in the laboratory by bringing a strong magnetic field around the source of radiation (Zeeman effect); they may also be greatly transformed by anomalous dispersion; and shifts of the lines can be induced by the application of pressure in the atmosphere enclosing the source. The existence of local magnetic fields in the sun has been demonstrated by Hale. There is quite as much reason to expect them in stars of early type in which the circulation may be more rapid, with more activity of ionized particles. In so far as the field is associated with sun-spots, we should expect similar effects in stars of the third spectral type in which many variables occur that have been supposed to show effects similar to sun-spots.

But the changes in the spectra of these binaries are ordinarily strictly periodic, with evidence occasionally of a secondary period. The cause of any magnetic effects thus needs to be also strictly periodic (usually short), which could hardly be the case with currents circulating in a stellar atmosphere. Hence the cause would have to be sought in some periodic approach of two celestial bodies,—which brings us back to a binary system with a strongly elliptic orbit. The mechanical explanation is thus the simpler and would seem to be necessary in either case.

As for anomalous dispersion, the arguments have been put forward persistently by Julius for some years past, and he has performed some beautiful experiments in the laboratory. He would use it to explain many solar phenomena, as well as spectroscopic binaries. Now it certainly does seem that anomalous dispersion must occur for rays passing from one star through the atmosphere of another, as in the case of the eclipsing variable stars of the type of *Algol*. But thus far the spectroscopic evidence seems to be lacking that it actually does take place; it gives no better explanation of spectroscopic binaries than the mechanical one.

The effect of pressure in stellar atmospheres is now being detected and measured, as already indicated, but here again we find no good reason for a periodic disturbance of pressure that does not involve the mutual action of two bodies. Furthermore the pressure-displacements are always toward long wave-lengths, but in the spectroscopic double stars we find large displacements toward the violet as often as toward the red.

It seems reasonable, therefore, to say that no adequate substitute has been found for the explanation of periodically double and periodically shifted lines as originally given by E. C. Pickering and by H. C. Vogel. Hence it seems necessary to believe that spectroscopic binaries are actually very common, and that theories of stellar evolution must provide quite as well for double or complex systems as for monarchies like that of our sun.

There are, however, certain kinds of displaced and changeable stellar spectra which are probably not a result of the Doppler-Fizeau principle: I refer in particular to the *novae* or temporary stars. *Nova Aurigae* of 1890-1 was the first object of its kind to have its spectrum success-

fully photographed so that radial velocities could be determined, if present in the system. At that time, when the first spectroscopic binaries had just been discovered, it was natural to try to account for the displaced bands and lines within them on that principle. The velocities indicated for the components were very large, beyond precedent; but mere amount of velocity ought not to be regarded as a serious difficulty. Since we know that some stars have a translation of 100 or even 200 km per second, why should we hesitate to accept a velocity of 1000 km? We reject the Doppler-Fizeau principle as a sufficient explanation in case of the *novae* because all of the dozen stars of that sort, observed spectrographically, have exhibited the same spectrum, with the bright component of the double lines always displaced toward the red from the dark component. This uniformity is beyond all "probability" as the result of the chance intrusion of a star (previously invisible) into a cosmical cloud. The transformation of such spectra into that of a nebula, after some months of decline in brightness, also calls for some physical explanation wholly aside from mechanical motion or collision. No satisfactory hypothesis for the phenomenon has yet been given; we need new information from the laboratory more than we need spectroscopic data from additional *novae*.

The hearer may justly complain of the pessimistic tone through all of these remarks, but the way is often made for progress by recognizing fully the defects of present procedure.

A splendid harvest is beginning to be gleaned from the systematic line-of-sight work of the past two decades. The results have already exceeded expectations. Of the utmost importance was the establishment as a fact that the successive spectral types from the helium stars (B), through the Sirian (A), the Procyon type (F), and Solar (G), show a progressive increase of intrinsic velocity (for B, 6 km; for A, 10 km; for F, 14 km; for G, 15 km; for K, 17 km). This was gradually suggested by various observations, but was clearly enunciated by Campbell and independently by Kapteyn. Then it was fully confirmed by the lamented Lewis Boss from the study of the proper motions across the line of sight of the stars according to spectral type.

(We may well recall at this time that it was at no small sacrifice to his personal strength and in the midst of a bereavement that Professor

Boss consented to remain in Washington for some days last winter to fulfill a promise to present to this section a general account of his far-reaching investigations of stellar motions.)

Most interesting speculations, tending to widen immensely our cosmological horizons, have already been advanced to account for the progressive change of speed with type, and the matter is only beginning to receive the attention of philosophers.

The study of spectroscopic binaries and their orbits has advanced enough so that important principles can be enunciated regarding them.

A new discussion of the motion of the sun, based on Lick observations of over a thousand stars, has been made by Campbell.

The determination of radial velocities has co-operated indispensably in proving the existence of swarms of stars, moving toward a definite convergent point, as discovered by Lewis Boss and Benjamin Boss. These give evidences of the operation of a common cause upon bodies immensely distant from each other and open new avenues of conception.

Finally the radial velocities already measured are yielding invaluable evidence in the cosmogonic studies of the great star drifts to which many of the ablest minds are giving attention.

Important as all these products of the spectroscopic measurement of the velocities of stars in the line of sight are, we must not forget that we thus obtain only one component of the velocity. To get the true speed and direction in space of the motion of any individual star, we must know both its motion across the line of sight (in seconds of arc per century) and its distance from our sun. With both these known we can convert the cross-motion into kilometers per second and then compound it with the radial velocity, obtaining the true velocity sought. The most difficult point involved is the knowledge of the star's distance, and it is upon this problem, at the very limit of the power of the most refined practical astrometry, that the activity of the most efficient instruments should be and is being directed.

In an important paper, forming Bulletin No. 214 of the Lick Observatory, Dr. H. C. Wilson gives as accurately as possible the real motions of 100 stars of large proper motion whose radial velocities have been determined. As intimated, the uncertainty comes from the uncertainty as to the true distances of the stars concerned. He therefore derives

the coördinates of the point which the star is approaching, together with its true velocity in space, for three assumed values of its parallax. and for the best actual determination available.

The diversity produced in the results by the different values of parallax adopted, may be best illustrated by a random quotation from his tables.

Star	Parallax	Point approached		True Velocity
		R.A.	Dec.	
	″	°	°	
Arcturus	0.05	160	—56	205 km. per second
"	0.10	167	—57	97
"	0.20	184	—56	44
β Comae	0.05	80	+52	108
"	0.10	82	+65	54
"	0.15	144	+86	31
Procyon	0.25	314	—28	21
"	0.30	307	—20	19
"	0.35	302	—13	19

Thus for *Arcturus* an uncertainty in the parallax produces a great uncertainty in the true velocity, while the direction of motion is well established. For β Comae both the point of approach and the true velocity are seriously affected by a change in the assumed parallax. For Procyon, with its large parallax (actually believed to be about 0″.32), both direction and velocity are well determined.

The full realization of the value of the spectroscopic measures of the radial velocities of the brighter stars must therefore await the concentration of the best astronomical effort upon the measurement of the distances of the individual stars,—a task of sufficient difficulty and magnitude to stimulate our interest for years to come.

EXPERIMENTAL PROOFS OF THE EARTH'S ROTATION.

WILLIAM F. RIGGE.

In establishing the truth of the Copernican system, professors of astronomy are apt to look upon Foucault's pendulum as the one experimental proof of the earth's diurnal rotation. They may also possibly refer to the gyroscope, to the deviation of projectiles and of bodies falling from a great height, and to trade winds and ocean currents; but if they do, it is rather by way of confirmation than of genuine proof. As leisure and means are wanting for special research, they may settle down to the conviction that Foucault's pendulum is the only true experimental proof that has ever been advanced.

The writer hastens to admit that he had always shared this conviction with his colleagues until about a year ago, when he received from his former director at the Georgetown College Observatory, Father Hagen, what is officially called Volume I, No. 1, New Series, of the Publications of the Vatican Observatory. It is entitled "La Rotation de la Terre, Ses Preuves Mécaniques Anciennes et Nouvelles, par J. G. Hagen, S. J., redigé en Francais par P. De Vregille, S. J." It contains a wealth of information upon the subject, together with two new and original proofs, which it has long been the intention of the writer to present in an abridged and popular form to the readers of this magazine.

The author begins by stating that all experimental proofs of whatever kind are based upon three fundamental principles, the motion of the centre of gravity, the constancy of areas, and *vis viva*, although all these three are ultimately reducible to the one of inertia. Under the first he classes Foucault's pendulum and the horizontal movement of projectiles. Under the second are all motions of projectiles and falling bodies, and notably the bent spring of Poinsot and the isotomeograph. The third comprise all complicated instruments, such as the compound pendulum and the gyroscope.

There are also three degrees of perfection in the experiments, inasmuch as they prove the earth's rotation qualitatively, quantitatively and with precision. For example, an experiment with Foucault's pendulum would be a qualitative proof, if the plane of the pendulum should appear to turn in the proper direction. It would be a quantitative proof, if it turned through the proper angle in the given time within the small percentage of error generally allowed in practice. It would

be a proof of precision, if the fact corresponded perfectly with the theory. Such a proof of precision, the author says, is to be found only in the method of Kamerlingh Onnes.

The chronological order, which is given together with the bibliography of the subject, is divided into five periods; the prehistoric, in which nothing of scientific value was actually accomplished, that of the fall of bodies, of the simple pendulum, of more perfect apparatus, and finally the modern period.

I. Falling Bodies.

1. *Free Fall.* If the earth turns on an axis, every point on it and in it moves in a circle, whose center is in this axis at the foot of the perpendicular dropped to it from the given point. The angular velocities of all points are necessarily the same, but their linear velocities are directly proportional to their distances from the axis. For this reason bodies on the top of a tower move eastward with greater speed than those at the bottom. The actual rotation of the earth is therefore proved by experiment qualitatively, if we can show that this difference of velocity exists and is in the proper direction. It is proved quantitatively, if we can measure its amount. The simplest method of doing this is to drop a body from a height and establish its eastward deviation.

One of the very first experimental efforts made to establish the earth's diurnal rotation was suggested by Mersenne about the year 1644 near Paris. It consisted in firing projectiles from cannons pointed towards the zenith. It was thought that the shots would fall in a definite direction. But they fell in all directions and to different distance. Similar failures met the experiments at Strassburg in 1770 and at Toulouse in 1851.

Guglielmini at Bologna in 1790 was the first to experiment with bodies falling from a height. He used lead balls accurately turned and polished. He suspended each one in turn by a thread attached to that point of the ball which was on top when it was floated in mercury. He cut the thread with a knife and allowed the ball to fall 90 feet. Unfortunately it was only after six months that he suspended a plumb line at the place in order to find the deviation of the balls from the vertical. He neither tells us from what point of the compass the threads were cut, nor the bearing of the sides of the tower.

Benzenberg repeated these experiments at Hamburg in 1802, using generally a fall of 235 feet. He observed during the day time, while his predecessor had worked after midnight. But he took the precaution to suspend his plumb line immediately before and after each set of falls, and to cut the thread half of the time from the north and the

other half from the south. The meridian line was found by means of a compass needle. The balls were an alloy of lead and zinc. As the extreme deviations of his balls from the vertical are nine times the mean distance of all and, as according to his own statement, the sun, coming out of the clouds at noon, upon one occasion, warmed the south side of his wooden tower so much as to throw his plumb line 1.5 lines towards the north, Benzenberg's results, like those of Guglielmini, cannot be considered to offer even a qualitative proof of the earth's rotation.

Benzenberg also dropped 40 balls in a mine at Schlebusch from a height of 262 Paris feet, but gives the results of only 28 of these. Gilbert says that neither of these two attempts of Benzenberg's have any scientific value. A more lenient judge, however, may find in his second one some general eastern tendency.

Reich experimented with a fall of 158.5 meters in a mine shaft at Freiberg in Saxony in 1831. He used two methods of suspending his balls. The first was to hold them with tongs or pincers, one jaw of which opened alternately to the north and to the south. The second was to heat them in boiling water and place them on a ring, through which they fell as they cooled and contracted. He also turned the tongs and the ring halfway round during each set of falls. His balls were made of tin, lead and even ivory, but most were of an alloy of tin, bismuth and lead. The theoretical value being 27.5 mm, he obtained a mean easterly deviation of 28.4 mm, an excellent result. His mean southerly deviation of 1.5 mm is sufficiently small in view of his experimental errors not to weaken in any way the theory of Gauss and Laplace, according to whom the meridional deviation is sensibly zero.

Hall in Cambridge, Mass., preferred the conveniences of a laboratory and the moderate height of 23 meters to the towers and deep shafts of his predecessors. His experiments took place between April 26 and July 25, 1902. He suspended his balls by a thread below a ring, pressing the ring down on them by a lever and counterpoise, and then burned the thread with a gas flame. Instead of letting the balls drop on a block of hard wood, as had been done heretofore, he caught them in a plate full of a mixture of soap, lard and wax. In turning the plate about its center, he could gather six balls into the corners of a regular hexagon. He recorded 948 falls.

He found an evident easterly deviation, the probable error of his determinations being less than the observed value. He attributed to his results only a feeble quantitative signification. His southerly deviation cannot be considered to be certain.

Hooke's trials before the Royal Society in London in 1680 have only an historic value. He affirmed that the fall of a heavy body would be more to the south than to the east. As the height used was only 27

feet and the theoretical easterly deviation less than half a millimeter, Gilbert declares him to have been under an illusion. Similar judgment must be meted out to other minor experimenters, whose names and results are scarcely worth mentioning.

It is, however, of interest to note some of the suggestions made in regard to the places and manner of experimenting with falling bodies. Laplace proposes the national observatory of Paris, where a height of 54 meters would give a theoretical easterly deviation of about 6 millimeters. Benzenberg in 1804 pointed to the Pantheon in Paris and to St. Peter's in Rome as ideal spots for such investigations, little dreaming that both places, at intervals of half a century, would furnish different and new proofs of the earth's diurnal rotation. Oersted, in writing to Sir John Herschel in 1846, calls upon the British Association to make these experiments. Gilbert says that there are not a few mine shafts of 300 meters for this work. Cajori in 1901 suggests the Washington Monument with its interior height of 165 meters.

2. *Impeded Fall.* It seems to have been a foregone conclusion that the greater the fall, the more accurate the results would be. Hall in 1902 was the first to content himself with the moderate height of only 23 meters, after having developed a scheme for the Washington Monument, and not having been allowed by the War Department to put it into execution. A reduction of the height does away with the influences injurious to the body's velocity, its rotation, and the resistance of the air. In fact even a modified Atwood's machine, which, as we know, diminishes the velocity of a falling body to any desirable extent, gives measurable results, as Father Hagen himself proved in 1911. In his later experiments the pulley was fixed, as it always is in Atwood's machine. This did away with two theoretical advantages, which a suspended pulley would have. It prevented the observation of the deviation of the rising counterpoise, as well as the reversibility of the experiment. These theoretical losses were, however, more than offset by the practical advantage of stability, with which neither unifilar nor bifilar suspension could compete.

A fall of 23 meters was used in the experiments. The weight was only 50 grams, while its counterpoise was three-fourths as heavy. The weight fell through an air-tight cylinder, at the bottom of which were two small windows, one on the north and the other on the east side, while the counterpoise ascended on the outside of the cylinder. The fall occupied ten or eleven seconds. As the counterpoise reached the top, its velocity was checked by its picking up a metallic plate, which was then held fast by a spring. As the weight also was thereby arrested and prevented from further falling, any deviation it had experienced would betray itself in a pendular swing, whose double ampli-

tude could be observed by a telescope. At every trial the first direction of this swing was invariably towards the east, and its extent was always noted the moment before the weight had ceased to fall. The mean of 66 easterly deviations was found to be 0.90 mm, 0.01 mm more than its theoretical value, with a probable error of 0.03. The mean of 22 southerly deviations was 0.01 mm, the probable error being nearly three times as great, so that these experiments lent no support to the persistent claim, which seems to be all but universal, that a southerly deviation must exist. This much-discussed meridional deviation of a falling body is nothing but the effect of the earth's centrifugal force, which has driven its surface fluids towards the equator and made the equatorial diameter about 26 miles longer than the polar. While the existence of this force is universally admitted, it has, however, never met with an experimental proof. Laplace and Gauss declared it to be practically insensible, and Bertram says that in latitude 45 degrees with a ten second fall it would not be more than the one-hundredth of a millimeter.

Puiseux's suggestion of two basins of mercury at different heights was tried in 1865 by Abbadie, who could see no measurable difference in the inclinations between one 10 cm below his telescope and another 10.5 meters below. Maillard's experiment is very original and very elegant from a mathematical point of view, although its execution leaves much to be desired. He took a vertical brass tube with an external diameter of 10 cm, and set it upon a glass cylinder 20 cm. long so that a paraffine float 5 or 8 mm in diameter might be observed near the bottom, when the water was allowed to run out of the tube. As this was done by means of two orifices one north and the other south, or one east and the other west, it was thought that an easterly and a southern deviation of the float might be observed. The results were, however, masked by too many practical difficulties.

II. The Pendulum.

When a pendulum is allowed to swing, we know that it does so under the influence of gravity alone and that this force acts in a vertical plane without any horizontal component. The plane in which the pendulum vibrates must therefore remain the same, and if it changes at all, the change must be only an apparent one and due to the real turning of the floor beneath it, the turning of the ground, and the turning of the whole earth. When a pendulum is swung in the northern hemisphere, the ground to the south of it moves eastward faster than the point beneath it, while the ground to the north moves with less eastern speed and relatively, therefore, to the west. The consequence is a turning of the ground to the left as seen from underneath the

pendulum, but as this is not evident to the eye, since all bodies and ourselves included are involved in it, the plane of the pendulum appears to turn to the right with a speed which varies inversely as the sine of the latitude.

Three kinds of pendulums have been used to prove the rotation of the earth. The first is called the simple pendulum, because it approaches to some extent to the usual physical definition of this instrument. When it swings in an approximately vertical plane, it is called a Foucault pendulum. When it swings in a nearly circular curve, it is a conical or Bravais pendulum.

The second kind of pendulum swings in a horizontal plane, and is called a Hengler pendulum.

The third kind, the compound pendulum, has so many varieties that it bears no particular name.

The ball of a Foucault pendulum is very much like a projectile thrown horizontally, which in virtue of its inertion deviates to the right, as Foucault himself remarked. While falling bodies can at best furnish only a qualitative proof of the earth's rotation, the pendulum may be made to give a quantitative one, indeed one experimenter has even succeeded in getting a proof of precision.

1. *The Foucault Pendulum.* The apparent change of the plane of vibration of an ordinary pendulum had been observed by Viviani in Florence in 1661, two centuries before it had found an explanation. And by a strange opposition of facts, Foucault developed the theory of this deviation, before he had made any experiment whatever. If he or Newton had known of Viviani's discovery, they would surely have found in it at least a qualitative proof of the earth's rotation.

Foucault's first experiment was made on Wednesday, January 8, 1851, at two o'clock in the morning, with a thread only two meters long and a ball of five kilograms in weight, hung from the vault of a cave, the amplitude of the vibrations being from fifteen to twenty degrees. He next used a thread eleven meters long, and finally, at the request of the prince president, Louis Napoleon, he performed the world-famed experiment in the Pantheon with a steel wire 1.4 mm in diameter and 67 meters long and a weight of 28 kilograms, the horizontal swing covering an extent of six meters. The upper end of the wire, instead of being directly attached or soldered, passed loosely through a draw plate set into the vertical slot of a steel plate. The horizontal deviation was one degree in five minutes or 2.3 mm at each vibration, as he had predicted, and it swung for about five or six hours.

As Foucault had suspended his pendulum in Paris in latitude 48° 51′, Lamprey's trial at Colombo in Ceylon, in latitude 6° 56′, offered a good verification of Foucault's law of sines. The mean of eleven observa-

tions gave a result differing three per cent from the theoretical value. If two observations made in the N.W. and S.E. direction are rejected, the agreement between fact and theory is perfect.

During the same year 1851 a Foucault pendulum was swung in Rio de Janeiro in the southern hemisphere, in which the deviation was in the opposite direction to that at Paris and Colombo. The weight was a hollow sphere of 10.5 kilograms, the thread was of linen without torsion, and the pendulum 4.365 meters long. It was found that between the plane of the meridian and that of the parallel of latitude, there were two invariable planes of oscillation in which there was no deviation. The report states that in half an hour the deviation was 5° 9′ towards the east in the meridian, and 5° 12′ towards the south in the parallel plane. The writer evidently intended these figures to mean hourly variations, since they are double the theoretical values for half an hour. The direction of the deviation is also ambiguously given, his words being "in the sense of the earth's rotation", which when taken literally would show that the deviation had always been in the wrong direction. It is an astonishing fact that no experiment of any scientific value has even been reported from the southern hemisphere.

Several observations seem to prove that the deviation was different in different azimuths. Thus at Oxford, where iron and lead weights of twelve pounds and a piano wire of 80 feet were used, the deviation was noticed to be accelerated as the plane of vibration approached the magnetic meridian, and to be retarded when it was at right angles to it. The coming and going of visitors also affected the results. It is very remarkable that steel wires proved to be more unmanageable than those of soft iron.

Secchi's experiments in Rome in 1851 developed an unexpected irregularity. His pendulum was 31.89 meters long and weighed about 28.5 kilograms. He used a soft iron wire 1.8 mm thick, and steel wires of 0.65 and 1.3 mm. The first gave the better results. An elliptic motion of the pendulum, which invariably began to show itself after an hour and a half, always took place in the same direction, which was that of the earth's rotation, thereby diminishing the angle of deviation. This peculiar phenomenon was attested to by many witnesses. Many, and Secchi himself, thought it was due, at least partially, to the initial velocity of the weight imparted to it by the rotation of the earth itself. The rigidity of the wire might also be a cause of it. Airy suggested an oval shape for the hole through which the wire passed, and an unequal taper of the wire. With a major axis, that is, a horizontal amplitude of one meter, the greatest minor axis of the ellipse observed was 20 mm. Secchi's results differed one-fifth of one per cent from their

theoretical value. He found no difference between vibrations executed in the meridian and in the prime vertical.

Garthe, in 1852, in the cathedral at Cologne, was the first to use a Cardan suspension. As its movable ring had a diameter of only 5 cm, while his pendulum was 50 meters long and weighed 17 kilograms, it introduced no sensible error. Nearly a thousand visitors came to see the experiments. The error was one-sixth of one per cent. Garthe does not mention any elliptic motion, although two oscillations extended over three hours fifty-two minutes, and the deviation amounted to 45 degrees. Nor does he speak of the Cardan suspensions whose two pairs of steel axes were not in the same plane.

Bunt in Bristol, instead of drawing the weight aside and securing it by a thread and then burning the thread, as all his predecessors had done, let it go by hand and tried by a side touch to give it an elliptic motion opposite to that he had last observed. After applying all the necessary corrections, he obtained a value correct to one per cent. Van der Willigen in Harlem in 1868 followed Bunt's method, his per-cent of error being 0.5.

2. *The Bravais Pendulum.* Bravais hung up a conical pendulum 10 meters long, in the large meridian room of the Paris Observatory. The weight was a copper cylinder full of mercury and weighed 10.5 kilograms. Below the pendulum was a space of about one and a half meters. This was occupied by a kind of clockwork which had one shaft set up vertically, directly under the point of support of the pendulum. A graduated bar extended at right angles to this shaft, and when the clockwork had been set in motion, it pushed the pendulum weight around in a circle. When the centrifugal force generated had swung the weight the desirable distance from the centre, the bar was arrested and then lowered, so as to be out of the way of the weight. The bar could be raised at any time and the distance of the weight from the centre measured in any direction, so that the exact shape of its trajectory could be determined.

The Bravais differs from the Foucault pendulum in this, that in it the deviation in azimuth cannot be observed, but there is instead a change in the time of a vibration. As a variation of space appeals more to our senses than one of time, the Bravais pendulum never met with popular favor, and seems to have been set up only once and that by the inventor himself. It has, however, two points of superiority over the Foucault pendulum, in that it is reversible, since it may be given a dextrorsal as well as a sinistrorsal revolution, and in that the time of a revolution or of a vibration may be lengthened or shortened at pleasure.

On account of the reversibility of his pendulum, Bravais was enabled to experiment with only one pendulum as well as with two

revolving simultaneously in opposite directions. In the first case he observed the time of vibration at a distance by means of a telescope, and then repeated the experiment with the motion reversed but with the same starting amplitude. In the second case he used two pendulums of 10.2 and 10.1 meters in length, and 0.7 meter apart, and noted the moments when their supporting wires appeared to be coincident in the telescope, once when they crossed the field of view from opposite directions, and again when they seemed to come from the same direction.

The practical difficulties of the Bravais were very similar to those of the Foucault pendulum. There was a noticeable change in the time of vibration in two azimuths at right angles to one another, and the circular trajectory always showed a tendency to degenerate into an elliptical one, the major axis of which always assumed a fixed direction. Bravais investigated these irregularities with great care and computed corrections for them, but he neglected those of the manner of suspension as insignificant. Although his results were of great value quantitatively, and within about four per cent of their theoretical value for a single pendulum and about one per cent for two pendulums, he did not think them sufficiently precise. It may be of interest to add that his ten meter pendulum experienced an acceleration or a retardation in azimuth of 11.43 seconds of arc in each second of time, one revolution occupying about 6.5 seconds.

To be Continued.

THE STORY OF THE ZODIAC.

EDITH R. WILSON.

[*Continued from page 158.*]

When we turn to the examination of Egyptian planispheres, we are met by a most perplexing variety of stellar forms which at first sight quite escape our recognition. Each Sign and Constellation appears, portrayed not only under its stellar but also under its mythical attributes which are distinctly Egyptian, while the whole astral company go sailing along the Ecliptic in boats, space being regarded, by our friends of the Nile, as a great abyss and the term, "Dweller in the Abyss," being a generic title for a planet or star. The most famous Egyptian zodiacs known to us are those of the Temple of Hathor at Denderah,—comprising the so-called "square" and "round" zodiacs,—and that of

the Ramesseum at Thebes; of these the latter is by far the most ancient. Lockyer, in his "Dawn of Astronomy," describes both and gives us an account of the opposing camps into which astronomers and archeologists were divided on the question of their antiquity, at a time when Champollion's recent discoveries had attracted the attention of the whole scientific world and especially that of French savants to the fascinating problems of Egyptology. But prior to the brilliant discoveries which mark the dawn of the nineteenth century in this field, attention had been called to Egyptian astronomy and the mysteries of Egyptian astro-mythology by several pioneers, first and most renowned of whom was the learned Jesuit, Athanasius Kircher (1602-1680), precursor of the modern study of Egyptian hieroglyphics. In Egypt, as Lockyer observes, we find no treatises on Astronomy, such as greet us in India and Babylonia (except it be their "Book of the Dead"). Our information is mainly derived from their monumental temples, pyramids, and tombs, which are covered within and without by a great variety of mingled astronomic and historic records whose association is often mutually helpful in interpretation.

The zodiacs of Denderah and Thebes, just alluded to, contain much more than a mere delineation of the twelve Signs. These figures are accompanied by a wealth of information which aid in dating their respective eras. The names of the months, then corresponding with particular Signs, are given, with those of the "Councillor Gods", or stars presiding over each, which, by their settings and risings, moved in an "eternal circuit between the infernal and supernal regions." The relation of these stars to the Equinoctial and Solstitial points and the dates of their heliacal risings, also furnish important data which, together with the orientation of the temple itself, permitting it to receive the light of sun or star through its long colonnades only at a very definite season and moment of time, enable us to form no uncertain approximation as to the date of their inscriptions.

The astronomer Biot's discussion of the zodiacs at Denderah and the Ramesseum seems to have been accepted by scientists as final, giving to the first the comparatively recent date of 700 B.C., but claiming for the latter an antiquity of over 3000 before Christ. For special reasons, indeed, he regarded it as representing the Spring Equinox of 3285 B. C. since from its tables we learn that the star Sirius at that time rose heliacally at the beginning of the Nile Rise, which the "minute studies of Biot and Oppolzer" indicate would have been possible as early as 3285 B. C. "Egypt is the gift of the Nile!" as Herodotus proclaimed centuries ago, and Sirius as the index star of its annual overflow occupied a place of paramount importance in the ancient kalendar of that nation. The Egyptian year began with the Inundation of the Nile at

the Summer Solstice, when the great festival of the first of Thoth took place, and the appearance of Sirius as its harbinger was greeted with acclaim. Lockyer claims to have found seven temples orientated to her rising, while Mariette translates for us an inscription at Denderah stating that Sirius, venerated as Her Majesty Isis-Hathor, "shines into her temple on New Year's day and mingles her light with that of her father Ra, the sun-god, on the horizon." But just as the slow precession of the equinoxes has caused the solar signs to slip back, one by one, so it has produced a gradual displacement of the Egyptian Index Star, once honored as "the great Sothis, Mistress of the opening year," until now, far from mingling her light with that of her father Ra at the Summer Solstice, she does not rise heliacally (technically 10° before the sun) until the 10th of August. This displacement was of course very slow, but as the length of the Egyptian year was not quite accurate, the coincidence of the Summer Solstice, the first of Thoth and the rising of Sirius, was not always exact even in ancient times. The Egyptians constructed their famous Sothic period to calculate the coincidences between the Sirian and their Tropical year. It was one of these coincidences as established by Biot for the latitude of Thebes, which led him to assign the exact date, 3285 B. C., for the Ramesseum Zodiac. In it we recognize the Bull, the Lion, and the Scorpion. We note too a sign suggestive of our Libra, which proves, however, to be a Nile measurer, a man with a nilometer measuring the height of the overflowing river. Cancer changes into the Tortoise, or to the Sacred Scarabeus, and also seems to have played a part in heralding the Nile flood.

The fullness and complexity of these temple zodiacs render them difficult matters for study by any but experts. We have, however, in the worship of certain stars and their relation to the ecliptic, an indirect witness to the age of Egyptian astronomy and its solar signs. After the gleaming Sirius, the dog star of the Nile, depicted and venerated under so many forms in dark browed Egyptian temples, the most renowned of these stars were Thuban, or Alpha Draconis, pole star of the third millenium before Christ, and perhaps Etanim, or Gamma, of the same constellation of the Dragon. Here again we are met by the results of precessional movement, for in the scaly folds of the great serpentine monster who figures on our star maps as "Draco," the pole of the ecliptic lies hidden. Around it swings, in slow cosmic revolution, of nearly 26,000 years, the pole of our little equator, producing not only equinoctial displacement but, even more obviously, a change of pole star, as it nods majestically to and fro. Shakespeare was quite at fault when he wrote of our Polaris:

"But I am constant as the Northern star,
Of whose, true, fixed, and resting quality
There is no fellow in the firmament."

Our little Cynosura did not begin his reign till after the Christian Era and, although he will continue to approach the exact pole, from which he is now about a degree and a quarter distant, until the year 2095, yet in celestial economics his sway is quite ephemeral, as he will then be obliged to recede in favour of other successive stars until, about 12,000 years hence, blue eyed Vega of the Lyre will occupy his throne.

Allusions to precessional effects are not unfrequently met with in literature. Thus Homer, in his Odyssey, makes the nymph, Calypso, instruct the returning Ulysses to "keep the Great Bear ever on his left," as he traversed the Mediterranean from the Pillars of Hercules to Corfu. Such a course, adopted now, would land the traveler in Africa, and has been cited as a proof of the poet's inaccuracy. Homer also speaks of his wandering hero as seeing Arcturus and the Pleiades setting late during a spring voyage and declares that the stars of Ursa Major never set in his latitude:

"Arctos, sole star that never bathes in the ocean wave."

All these apparent errors find their explanation in the changes wrought by precession, and fix the date of Homer's great Epics as between 1000 and 750 B.C. Again Dante, in the first Canto of his Purgatorio, laments the loss of the "quattro chiare stelle" of the Southern Cross, to our Northern latitudes, in the lines,—

"Oh, thou septentrional and widowed site,
Because thou art deprived of seeing these!"

recalling to our minds the impressive fact that this "Sign of the Son of Man" disappeared below the horizon of Jerusalem at about the time of the Crucifixion and will not reappear there for about 2000 years.

Looking backwards to almost 3000 B. C. we find Thuban, then the brightest star of the celestial Dragon, at its nearest point of approach to the North Pole, about ten minutes distant, nearer than our Polaris will ever be,—worshipped by the ancient Egyptians as sacred to Set, or Typhon, the god of darkness. By night and by day, it could be observed by them from the bottom of a great central passage built deep into the solid masonry of the Pyramid of Khufe or Cheops at Gizeh, so aligned as to point directly to the pole. The story of this famous pyramid-observatory and the uses to which it was put has been fully told by Professor Flinders Petrie, in his "Pyramids and Temples of Gizeh," leading

us to believe that for centuries, both before and after its nearest approach to the pivot of the sky, Thuban was watched as the Polaris of Old Nile.

Similarly there are tokens of a wide spread worship of Etanim—that star in the Dragon's head, from whose observation, long centuries later, the English astronomer Bradley gained his wonderful discovery of the aberration of light—known in primitive Egypt under the titles of Mut, Taurt-Isis, etc., as the wife of Set. Brightest of the northern stars available for temple orientation, her worship, if we can accept the conclusions of Lockyer and others, would carry stellar research in Egypt back to the times of King Mena and beyond! Taurt-Isis from her nearness to the pole may possibly have been used in her revolutions around that point, as a sort of dial hand, to tell the hours of a great star clock to the now mummied priests and astronomers of the dim past.

Apparently both Lockyer and Jensen trace a connection between the earliest star culture of Egypt and Babylonia, and even suggest a possible ethnical relation between the North and South Star worshippers of lower and upper Egypt and observers of a similar cult in the Accad and Sumer of early Babylonia. With keen discernment, Lockyer threads his way through the baffling mazes of Egyptian stellar myth, with its perplexing synonyms and variants, its strange animal configurations, to distinguish three schools of star worship. The most important in its relation to Babylonia, he finds to be that established at Annu or An, the ancient Heliopolis, seat of a primitive worship of Anubis, Set, or Typhon, god of night and darkness, typified by the circumpolar stars, before it became identified with sun worship as the city of Helios. The constellations sacred to Anubis, known to us as Draco and the two Ursae, were figured by the Egyptians as a hippopotamus and jackal,—and we have the myth of Horus (the young or rising sun), slaying these animals to avenge the death of his father, Osiris (the winter, or setting, sun), together with the historical occupation of Annu by a sun worshipping people, whom Lockyer identifies with the ancient Hor-she-shu (Followers of Horus), and the triumphal conversion of that city into a center of sun worship.

Turning now to Babylonia, for the counterpart of this celestial evolution, we trace its history back to a time when the land was divided into the northern highland province of Accad and the southern plain of Sumer or Shinar, inhabited by peoples diverse in race and tongue, as their recently discovered tablets, bearing Semitic and agglutinative inscriptions, testify. Sargon of Accad, whose date Sayce gives as 3800 B.C., united these two provinces into one, and for this ancient conqueror and patron of learning was compiled the great Babylonian treatise on

Astronomy "The Illuminations of Bel," in 72 books, a work dealing with eclipses, phases, and conjunctions of the planets, and other celestial phenomena, in such a manner as to indicate that materials for astronomic study had long been accumulating among the early dwellers in Babylonia. From this treatise, translated later by Berossus, priest of Bel at Babylon, as well as from other early inscriptions, we learn of their primeval triad of gods: Anu, Bil (or Bel,) and Ea (or Ia,) which, however popularized and personified later, are, in the "Illuminations of Bel," unmistakably cosmic abstractions, or close derivatives therefrom, Anu representing the upper heaven, or the heaven of heavens; Bil the visible sky, prince of the air and earth, later developing into a solar deity; and Ea symbolizing the "primordial deep," from which all things arose.

But more definitely than this, Jensen shows us that this primitive people associated Anu with the Pole of the heavens or ecliptic, Bil with that of the earth, or equator; for we have inscriptions explaining the course of the sun "in reference to Anu," or again, in reference to Bil." Moreover Bil was worshipped by night, for his priest was commanded to enter his temple "two hours after night-fall," and "putting on a stole in the presence of Bil," offer a prayer [Sayce, Hibbert Lectures]. Pierret, in his "Pantheon Egyptian," informs us that a hippotamus was the hieroglyph of Bil's later derivative, Baal. The worship of a sun god *by night*, offers an anomaly only explained by some gradual change of view point, such as that presented by the slow evolution of Bil, having his seat at the polar star and directing the daily course of the sun, into the actual sun god himself. Jensen confirms this view by giving us a Jackal or Leopard ideograph as associated with Anu, either "as god," or as "Pole of the Ecliptic," later developing also into a sun god, from his direction of the *yearly* course of that luminary. Such a derivation may best explain the fact that, from remotest antiquity, the symbol for deity in Babylonia was an eight-rayed star, while it is certainly remarkable that, at a date corresponding to the compilation of the "Illuminations of Bel," the poles of both ecliptic and equator, should have been found within the same constellation, our own celestial Dragon.

We could trace this recognition and veneration of the two poles, in early astronomy still farther, by a return to that of China, itself the Empire of the "Yellow Dragon," which placed the "Palace of the heavenly Emperor" in Draco, and whose astronomers, according to Bailly, guard a temple in the royal palace at Pekin consecrated to the "god Pe-tao," literally, the "North Stars." With such clear understanding of the position and relation of the two celestial poles, we may readily surmise that the dwellers in Accad and Sumer, had early mapped out the course pursued by the sun itself; and not only do we find this to be the case, but recognize

in their zodiac the prototype of our own, Lenormant claiming all but one of our present Signs to have been identified on cuniform tablets, cylinders, or monuments, thus confirming the testimony given centuries before by Diodorus Siculus, who tells us that the Chaldeans recognized twelve ruling gods, each presiding over one sign of the zodiac and one month of the year. A passage from the Babylonian Epic of the Creation as translated by Lenormant refers thus to Anu's supervision of the zodiac and its divisions. "Excellently he (Anu) made the mansions, twelve in number, for the great gods. He assigned to them stars and he established fixedly the Seven Stars (?) He fixed the time of the year and determined its limits. For each of the twelve months, he fixed three stars from the day when the year begins until its end. He determined the mansions of the planets to define their orbits by a fixed time, so that none of them may fall short and none be turned aside. He placed the abodes of Bel and Ea *near his own.* He made Nannar (the moon) to shine and he fixed the seasons of its nocturnal phases which determine the days," etc. In connection with the Signs of the Via Solis, we have repeated in another form, the Egyptian allegory of Horus, the youthful sun god vanquishing the powers of darkness. This is given us in the Babylonian Epic of Creation, where Marduk, Son of Ea, conquers the demons of Tiamat. In the Babylonian myth, however, there is no thought of circumpolar stars as symbolizing darkness. The demons slain are those of the lower, or *adverse*, half of the zodiac, typifying the winter solstice and the annual decline or death of the sun.

But another thought is outlined here, which meets us more plainly in the Chaldean Epic of the Deluge. The adverse signs of the zodiac and the demons of Tiamat (herself a personification of the great deep,) are not only winter, but *water* signs, the Scorpions, the Goat-fish, and the Fishes. The poem is "arranged throughout on a clearly astronomical principal," its twelve books each corresponding in subject to one sign

Thus far we have stood on apparently firm ground as to zodiacal data, the Taurine era of the Vernal Equinox being definitely fixed within certain limits. It is believed, however, by certain high authorities that the primeval zodiac was composed of six signs only, the original Taurus having extended to the "Fish of Ea", or double his present length, the sign Aries having been subsequently interpolated. This, it is suggested, would account for both these animals having been depicted at half length only, and also might considerably modify the argument for the antiquity of our solar belt, had the equinox been found in the latter part of Taurus at its formation. But, apart from the improbability of the original devisors of the zodiac placing the equinox in the middle or at the end of the sign, instead of at its beginning, this argument seems precluded by the distinct mention, in all early astronomies, of four royal, or guardian stars, marking the four cardinal points of the sky, or so

nearly so as to herald the sun's occupancy of the same. These were ruddy Aldebaran, in the head of the Bull, at one point of the V-shaped group, known to us as the Hyades; Regulus, heart of the kingly Lion; Antares, of ill omen, in the baneful Scorpion; and Fomalhaut in the Southern Fish. They have long since abdicated their starry thrones, or rather have been dethroned by the westward movement of the equinoxes, and now we have no bright stars marking the cardinal points. But if we turn the zodiac back through an angle of about 60 degrees we shall find our four "Guardians" approximately coincident—a coincidence which brings us definitely back to the third millenium B. C. Yet more, we are told that these stars were used in remote antiquity to announce, by their rising in the white dawn, the arrival of the day-king at the four important mile stones of his annual circuit. They were his "avant couriers" his heralds who by their heliacal risings, at these dates, proclaimed: "Awake, O Earth! His Vernal (or Solstitial) Majesty is at hand." Thus, especially, we have Aldebaran, known in Accadian nomenclature as Ku, I-ku, or I-ku-u, the leader, Star of stars, and as Dilgan, Messenger of Light, or as Dil-kar, Proclaimer of the Dawn, and again as Iyutha, meaning perhaps the Opener. All of which names were successively appropriated by other stars, or star groups, as Aldebaran's herald-function ceased. But when this star rose an hour before the Vernal Sun, that august luminary must literally have stood at the "golden horns" of the Bull, as he did about 4500 B.C! Schiaparelli, in his "Astronomy of the Old Testament" quotes a dispute among certain Rabbinical authorities, as to whether the title Iyutha belonged of right to Aldebaran, Capella, or to some other star, these dignities apparently failing to grasp its generic character. Capella, which is a northern, not a zodiacal star, was indeed known as Iyutha and as Dilgan, not as heralding the Vernal sun-rise, but because, by its relation to the Vernal New Moon, at sunset, it indicated the beginning of the year from about 2000 to 700 B.C.

Professor Maunder, Superintendent of the Greenwich Solar Observatory, in his forcible article on the "Triad of Stars,"* supplies us with another date in Euphratean Astronomy, from a similar use of two earlier stars. About 4000 B.C. the thin crescent moon, lying cup-like on its back, low in the west, between the two twin stars Castor and Pollux, would have indicated the new moon nearest the Spring Equinox, and as the day began at evening and the month with the new moon, the dawn of the first day of the first month of the new year. Tablets bearing these symbols found near Ur, city of the Babylonian moon god, are thus full of significance, and from them Professor Maunder argues

* Popular Astronomy, Vol. XVI: No. 7, page 403.

persuasively that the famous Babylonian "Triad of Stars," later supposed to refer to the sun, moon and Venus, was originally simply a hieroglyph of the opening year.

But to return to the Babylonian kalendar, we are now asked to take one farther step—this time somewhat of a leap in the dark. Both Josephus and Berossus assert dogmatically that astronomy was studied by the Antediluvians—Gore extending their lives for this express purpose, that they might verify certain astronomic periods. "They were the inventors", writes the Jewish historian, "of that peculiar sort of wisdom which is concerned with the heavenly bodies and their order," and the Chaldean writer emphatically repeats the same. However provocative of a smile such statements may appear to the casual reader, (although, abstractly speaking, it would seem more remarkable that men should pass well nigh a millenium upon earth without observing the stars, than the reverse,) astronomers and archeologists have not scorned to examine their claims. Cassini, of the Paris Observatory, took up the question of the six hundred year period, alluded to by Josephus, and found it to be a true period of solar-lunar commensurability, in which 7421 lunar revolutions of 29 days 12 hours 44 minutes and 23 seconds correspond to six hundred solar revolutions of 365 days 5 hours and 51 minutes and 36 seconds.

François Lenormant devotes an important chapter of his "Beginnings of History" to Berossus' "Fragment" on the Ten Antediluvian Patriarchs of Chaldea. Briefly, he gives the names of these worthies, as chronicled by Berossus, corrected, where possible, by the original form as found on cuneiform inscriptions, noting the traditions or legends connected with each, and the fact that each life, or reign,—for they were regarded as patriachal kings,—was supposed to correspond in duration with the passing of a zodiacal sign, the early Euphratean signs having been somewhat unequal in length to accord with the longevity of their representatives. Parallel with this account, Lenormant presents a table of the Accad-Sumerian months in which is noted not only the name and solar sign, but the event commemorated by each, with its protecting deity. According to a tradition repeatedly found among primeval peoples, the world was in some sense created under the protection of the sign Aries, which in this regard is called "Lu-lim", the Leader Ram. The Accadian name of this creation-month, "Bara-ziggar," is rendered the "Altar of the demiurge" or simply, "the Altar"; Anu and Bel preside over it. Adin-ru, the Chaldean Adam, appears in the second month, whose title, "Gud Sidi", signifies the Propitious Bull, whose sign is the stellar Taurus, and whose protecting deity is Ea, Lord of mankind. The third month is that of the "Brother Enemies". It also perpetuates the foundation of the first city. Its sign is alternatively two twin children,

or a pile of bricks. Again we have the month Su kul-ga, "The Gift of the Seed," the word "kul" referring, Lenormant tells us, to animate, not vegetable matter. The month of the "Message of Ishtar" is connected with the Sign of the Virgin, represented by a Sheaf of Wheat. Finally the eleventh month brings us to Hasisatra, the Chaldean Noah. Its appropriate title signifies the "Curse of Rain". Its sign is Aquarius, its titular deity, Ramman the Inundator. The twelfth zodiacal sign Pisces presides over the month "Se-kin-tar", the Deposit of Vegetable Seed, the patronage of the Seven Great Gods. However we may be disposed to regard the statements of Josephus and Berossus as to the astronomical attainments of the Antediluvians, or whatever view we may take of Lenormant's presentation of the latter's "Fragment", and of the exact date of the early Euphatean kalendar, we can hardly escape the conviction that it was framed by astronomers who were also the historians of the nation and who sought to perpetuate primitive traditons by stellar associations.

We may take exception to the remote dates claimed by ancient astronomers and urged by some modern ones, but the conception which these claims present to us of prehistoric man nobly engaged in stellar research, occupied with "that peculiar wisdom which is connected with the heavenly bodies and their order," is certainly an inspiring one. A recent writer of repute alludes to it in a tone somewhat at variance with the evolutionary theories of our day. "In what land," he ironically asks, "can our hairy, arboreal ancestors—as the current anthropology calls them—have so far lifted their thoughts from the gathering of nuts and edible roots for daily food, as to feel an intellectual interest in the far off astral world and because of this interest have proceeded to distinguish the planets from the stars that never wander, and, most remarkable of all, to invent that zodiacal chronometer whose months are double milleniums, and whose year is more than 25,000 of our years? No modern has ever suggested a substitute for it, or made any improvement in it, but had it as yet never been thought of, few persons now living in any one of our most civilized nations would be likely to invent it. What learned and ingenious reader of this sentence believes that, if uniformed as to any previous effort in this line on the part of earlier men, he himself would have been the first to chart out the ecliptical zone of the heavens, defining within it the lunar mansions, the solar stations, and backgrounding them all with a sexagesimally divided and subdivided scale of twelve equal parts, on which the minutes of the progress of every planet, and the ages of the precession of the equinoxes could be measured, each with equal ease, and both with absolute accuracy?"*

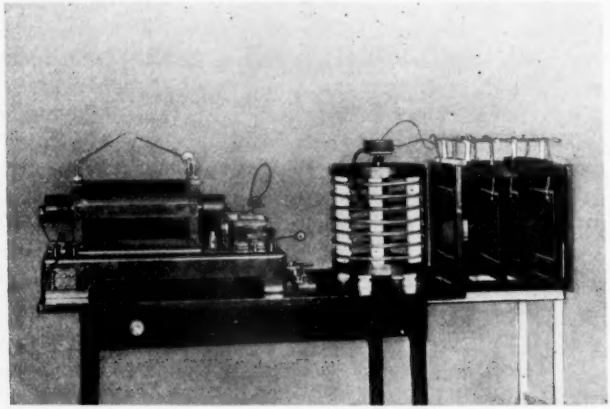
* The Earliest Cosmologies pp. 120-123. William Fairfield Warren L.L.D. S.T.D. Member Royal Asiatic Society; President Boston University 1873-1903 etc. See also Professor Maunder in Littell's Living Age, Vol. 227, p. 618, and Professor Newcomb's statement, POPULAR ASTRONOMY p. 16.

A WIRELESS TIME SERVICE.

E. A. FATH.

The idea of using radio-telegraphic signals as a means of transmitting time and making determinations of longitude without the continuous metallic circuit was advanced as soon as the possibility of wireless signals was demonstrated. This idea has been worked out to some extent in Europe and longitude determinations have been made. For some time too the Eiffel Tower station in France and the Norddeich station in Germany have been sending out time signals for the use of shipping on the Atlantic and it is reported that such a system is to be made world-wide in the near future.

In this country little has been done in this direction up to the present time, and, so far as known, the wireless time service briefly described below, is the first serious attempt to establish here a permanent time service by means of electric waves.



SENDING APPARATUS FOR WIRELESS TIME SIGNALS.

The plan originated with Professor C. A. Culver of the department of physics of Beloit College. After he and the writer had gone over the ground with some care and had tested various plans the present system resulted.

It will hardly be necessary to describe the methods of time determination for readers of POPULAR ASTRONOMY and we shall therefore begin with the standard time clock. This clock in the observatory is connected by wire, through a system of relays, to the wireless apparatus located in Science Hall. The accompanying cut shows the radio-transmitting equipment as it was in February, 1913. At the left is seen an induction coil which is used as an open core high tension transformer. It is supplied with alternating current from the local lighting system. This current has a frequency of 60 cycles and a voltage of 110. The transformer changes the voltage to about 30,000 and charges the high tension condenser seen at the right. The condenser discharges through the customary spark gap and the helix in the center, which is the oscillation transformer. This latter device changes the frequency from 60 to several hundred thousand per second. The aerial from which the electric waves are radiated into space is 400 feet in length and is connected with the oscillation transformer. The standard time clock at the observatory thus controls the current which actuates the high tension transformer and hence the output of electric waves. At each beat of the clock a train of electric waves is radiated into space. Each such group of waves is heard as a single dot at a receiving station.

For the present the following series of signals is sent out daily. At 2:55 p.m. the clock is switched into the circuit and each beat sends out into space a group of ether waves. The 59th beat of each minute is omitted up to 2:59:50. There is then an interval of ten seconds followed by a single beat. This beat marks 3:00:00 p. m. and may be considered the essential signal.

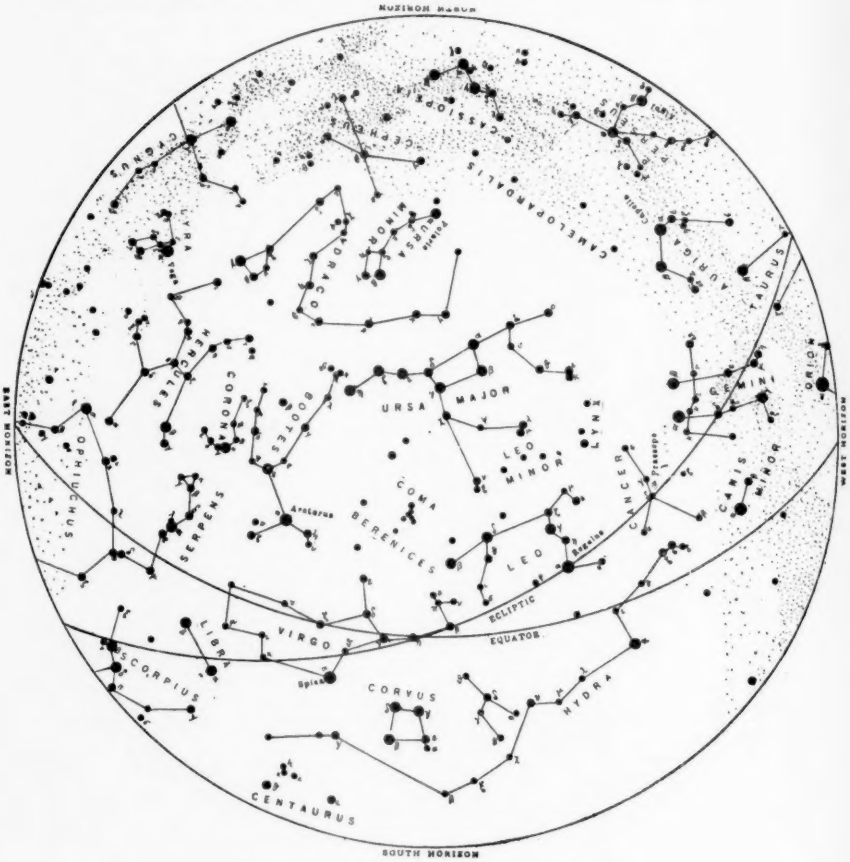
This time service is available within a radius of 150 miles of Beloit and has been in operation since November, 1912. Its purpose is to obtain data of scientific value from many receiving stations which have agreed to coöperate, and to be of some service to the region in which the college is located.

Various changes, especially in the wireless equipment, are now being made and it is expected soon to have the entire system in accord with the best modern practice.

Smith Observatory,
Beloit College, Beloit, Wis.

PLANET NOTES FOR MAY, 1913.

The sun will move northward about seven degrees during the month and by the end of the month will have reached almost its farthest position north. Its path eastward lies in the constellations Aries and Taurus. It passes the Pleiades and by the end of the month will be very near Aldebaran.



THE CONSTELLATIONS AT 9:00 P. M. MAY 1, 1913.

The phases of the moon for the month are as follows:

New Moon	May 6 at	2 A.M.	C.S.T.
First Quarter	13 "	6 A.M.	"
Full Moon	20 "	1 A.M.	"
Last Quarter	27 "	6 P.M.	"

Mercury, at the beginning of the month, will be visible in the southeast just before sunrise. It will move rapidly toward the sun and will soon become invisible It will be at a considerable distance south of the sun reaching its greatest heliocentric latitude south on May 9.

Venus will be too near the sun to be observed at the beginning of the month. It will be moving westward until about the middle of the month. At the end of the month it will be near a period of greatest brilliancy. At this time it will cross the meridian more than two and a half hours before the sun. Because of its great brilliancy it will at this time be possible to see with the naked eye this planet cross the meridian. This requires a very clear sky and it is necessary to know the exact spot to which to direct the vision to see it. For those who have telescopes this may easily be found by setting the circles according to the position given for the planet at the time the observation is to be made.

Mars will be in perihelion on May 18. In its motion in the sky it will follow the sun rather rapidly towards the east. It will be coming into better position for observation, each day rising a little earlier than on the preceding day. It will also be approaching the earth during the month.

Jupiter will move eastward for the first few days of the month and then have a retrograde motion for the rest of the month. It will consequently be getting quite far from the sun and at that end of the month will cross the meridian a few hours before sunrise. It will therefore be in fairly good position for observations.

Saturn will be in conjunction with the sun on May 29 and hence will not be visible during the month.

Uranus will be visible in the southeast in the early morning. It will cross the meridian a few hours before sunrise.

Neptune will move eastward less than three minutes of time during the month. It will be visible low in the west just after sunset.

Phenomena of Jupiter's Satellites.

CENTRAL STANDARD TIME.

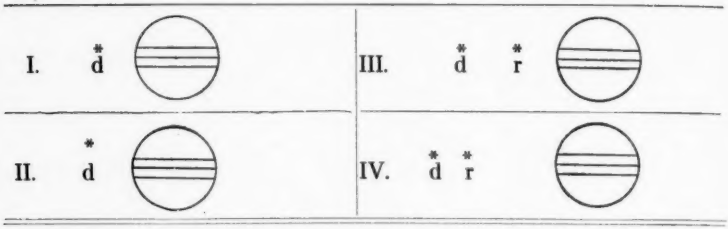
1913	h	m			1913	h	m		
May 2	13	24	III	Sh. In.	May 16	13	27	II	Oc. Re.
4	14	26	I	Ec. Dis.	19	15	20	I	Sh. In.
5	11	34	I	Sh. In.	20	11	36	III	Ec. Dis.
4	12	43	I	Tr. In.	20	12	42	I	Ec. Dis.
5	13	51	I	Sh. Eg.	20	14	35	III	Ec. Re.
5	15	1	I	Tr. Eg.	21	10	46	I	Tr. In.
6	11	28	III	Oc. Re.	21	12	6	I	Sh. Eg.
6	12	20	I	Oc. Re.	21	13	4	I	Tr. Eg.
7	11	34	II	Sh. In.	22	10	23	I	Oc. Re.
7	12	3	IV	Oc. Re.	23	11	2	II	Ec. Dis.
7	13	53	II	Tr. In.	25	10	41	II	Tr. Eg.
7	14	22	II	Sh. Eg.	27	14	35	I	Ec. Dis.
12	13	27	I	Sh. In.	28	11	42	I	Sh. In.
12	14	32	I	Tr. In.	28	13	33	I	Tr. In.
13	10	48	I	Ec. Dis.	28	14	0	I	Sh. Eg.
13	11	50	III	Oc. Dis.	28	14	51	I	Tr. Eg.
13	14	8	I	Oc. Re.	29	12	10	I	Oc. Re.
13	15	6	III	Oc. Re.	30	13	36	II	Ec. Dis.
14	11	17	I	Tr. Eg.	31	3	33	III	Tr. Eg.
14	14	10	II	Sh. In.					

Note:—In., denotes ingress; Eg., egress; Dis., disappearance; Re., reappearance; Ec., eclipse; Oc., occultation; Tr., transit of the satellite; Sh.. transit of the shadow

Satellites of Jupiter, May, 1913.

WASHINGTON MEAN TIME.

Phases of the Eclipses of the Satellites for an Inverting Telescope.



Configurations at 15h 0m for an Inverting Telescope.

Day	West							East							
1			4·			·2	○		·1		3·				
2		4·				·1	○	3·^{2}							
3		·4			3.		○	1·	2·						
4			·4	3·		2·	·1 ○								
5	○1·			·4		·3	·2 ○								
6					·4		○ ^{3}·$_{1}$			·2					
7						1·	○ ^{4}·$_{2}$				·3				
8					·2		○		·1	·4	3·				
9					1·		○ ·2	3·				·4			
10					3·		○	1·	2·				·4	·	
11				3.		2·	·1 ○							·4	
12					3·		·2 ○	1.					4·		
13							○			·2		4·			·1● ·3●
14						1·	○ 2·				^{4}·^{3}				
15					2·		○ 4·		·1		3·				
16					4.	1.	○			·3					·2●
17				4·		3·	○			1·	2·				
18			4·		3.		$_{2}$·^{1} ○								
19		4·			·3	·2	○	1·							
20			·4				○			·2					·1● ·3●
21				·4			1· ○	2·		·3					
22					·4	2·	○	·1			3·				
23						1·^{4}	○			3·					·2●
24						3·	○	·4	1	2·					
25					3·		·1 2·	○				4·			
26					·3	·2	○	1·					4·		
27						·3	·1 ○			2·				·4	
28	○1·						○	2·			3·			4·	
29						2·		○ ·1				·3	4·		
30						1·	·2 ○				3·	4·			
31							3· ○			·1 $_{4}$·^{2}					

The Lunar Eclipse March 21-22.—The total eclipse of the moon on the morning of March 22 came off on schedule time. At Northfield the black shadow was distinctly seen on the S.E. edge of the moon at 4:15 A.M.. Central Standard Time, and the entire disk was covered at about 5:12. A faint glow still remained on the west edge of the moon at 5:16. After totality the brightening of the sky due to the approaching dawn soon obliterated all trace of the eclipsed moon. Observations were made only with the naked eye.

VARIABLE STARS.

Approximate Magnitudes of Variable Stars on March 1, 1913.

[Communicated by the Director of Harvard College Observatory, Cambridge, Mass.]

Name.	R. A. 1900. h m	Decl. 1900. ° ′	Magn.	Name.	R.A. 1900. h m	Decl. 1900. ° ′	Magn.
X Androm.	0 10.8	+46 27	<13.0	R Aurigae	5 9.2	+53 28	11.0*d*
T Androm.	17.2	+26 26	<12.0	S Aurigae	20.5	+34 4	9.0
T Cassiop.	17.8	+55 14	11.4*d*	W Aurigae	20.1	+36 49	12.6 *i*
R Androm.	18.8	+38 1	6.6	S Camelop.	30.2	+68 45	8.5
Y Cephei	31.3	+79 48	10.8 *i*	U Aurigae	35.6	+31 59	11.6 *i*
U Cassiop.	40.8	+47 43	<12.0	SU Tauri	43.2	+19 2	9.8
RW Androm.	41.9	+32 8	8.1 *i*	Z Tauri	46.7	+15 46	<13.0
X Sculptoris	44.7	—35 28	9.0	RU Tauri	46.9	+15 57	<12.0
RR Androm.	45.9	+33 50	8.6	U Orionis	49.9	+20 10	10.6
RV Cassiop.	47.1	+46 53	11.9*d*	V Camelop.	49.4	+74 30	9.4 *i*
W Cassiop.	49.0	+58 1	9.7	Z Aurigae	53.6	+53 18	9.5 *i*
U Androm.	1 9.8	+40 11	9.5	V Monoc.	6 17.7	— 2 9	8.0
– Androm.	10.4	+41 12	13.7	U Lyncis	31.8	+59 57	10.0
S Piscium	12.4	+ 8 24	<12.0	S Lyncis	35.9	+58 0	13.8
S Cassiop.	12.3	+72 5	13.7	X Gemin.	40.7	+30 23	<12.0
RZ Persei	23.6	+50 20	13.8	W Monoc.	47.5	— 7 2	11.0
R Piscium	25.5	+ 2 22	8.7*d*	Y Monoc.	51.3	+11 22	<12.0
RU Androm.	32.8	+38 10	10.6	X Monoc.	52.4	— 8 56	7.8
Y Androm.	33.7	+38 50	<13.0	R Lyncis	53.0	+55 28	8.7
X Cassiop.	49.8	+58 46	12.8	RS Gemin.	55.2	+30 40	12.2
R Arietis	2 10.4	+24 35	8.1	V Can.Min.	7 1.5	+ 9 2	<13.0
W Androm.	11.2	+43 50	11.1*d*	R Gemin.	1.3	+22 52	11.6
Z Cephei	12.8	+81 13	11.3*d*	R Can.Min.	3.2	+10 11	9.7*d*
o Ceti	14.3	— 3 26	5.9 *i*	S Can.Min.	27.3	+ 8 32	8.1 *i*
S Persei	15.7	+58 8	8.1	T Can. Min.	28.4	+11 58	11.0
RR Persei	21.7	+50 49	<14.0	U Can.Min.	35.9	+ 8 37	13.0
RR Cephei	29.4	+80 42	12.4	U Puppis	56.1	—12 34	<11.0
R Trianguli	31.0	+33 50	7.2	R Cancri	8 11.0	+12 2	9.2 *i*
W Persei	43.2	+56 34	9.5	V Cancri	16.0	+17 36	7.8
U Arietis	3 5.5	+14 25	8.4	T Lyncis	16.4	+33 51	11.0
X Ceti	14.3	— 1 26	10.4*d*	RT Hydrae	24.7	— 5 59	8.8
Y Persei	20.9	+43 50	9.2*d*	X Urs. Maj.	33.7	+50 30	<12.0
R Persei	23.7	+35 20	13.2	S Hydrae	48.4	+ 3 27	11.4*d*
R Tauri	4 22.8	+ 9 56	11.4*d*	T Hydrae	50.8	— 8 46	<10.0
W Tauri	22.2	+15 49	10.3 *i*	T Cancri	51.0	+20 14	8.4
T Camelop.	30.4	+65 57	8.8	X Hydrae	9 30.7	—14 15	<11.0
X Camelop.	32.6	+74 56	8.1*d*	Y Draconis	31.1	+78 18	13.3
R Orionis	53.6	+ 7 59	9.2	R Leo.Min.	39.6	+34 58	8.3*d*
R Leporis	55.0	—14 57	7.0	RR Hydrae	40.4	—23 34	9.3

Approximate Magnitudes of Variable Stars on March 1, 1913

Continued.

Name.	R. A. 1900. h m	Decl. 1900. ° ′	Magn.	Name.	R.A. 1900 h m	Decl. 1900 ° ′	Magn.
R Leonis	9 42.2	+11 54	6.7 *i*	R Cor. Bor.	15 44.4	+28 28	5.9
X Leonis	45.6	+12 21	<12.0	X Cor. Bor.	45.2	+36 32	<11.0
R Urs.Maj.	10 37.6	+69 18	12.6	RU Herculis	16 6.0	+25 20	<11.0
V Hydrae	46.8	—20 43	7.2	W Cor. Bor.	11.8	+38 3	10.9 *i*
W Leonis	48.4	+14 15	<12.0	R Urs. Min.	31.3	+72 28	9.7
S Leonis	11 5.7	+ 6 0	<12.0	R Draconis	32.4	+66 58	12.0
RU Urs. Maj.	36.4	+39 2	<12.0	RR Scorpii	50.2	—30 25	10.9
X Virginis	56.7	+ 9 38	10.3	T Draconis	17 54.8	+58 14	<11.0
R Com. Beren.	59.1	+19 20	<11.0	V Draconis	56.3	+54 53	<13.0
T Virginis	12 9.5	— 5 29	<11.0	T Herculis	18 5.3	+31 0	11.4*d*
R Corvi	14.4	—18 42	<10.0	U Draconis	19 9.9	+67 7	13.5
T Can. Ven.	25.2	+32 3	9.5 *i*	R Cygni	34.1	+49 58	8.6*d*
T Urs.Maj.	31.8	+60 2	10.8*d*	RT Cygni	40.8	+48 32	6.9
R Virginis	33.4	+ 7 32	8.5 *i*	ST Cygni	20 29.9	+54 38	10.0
RV Draconis	33.2	+66 8	11.0	X Cephei	21 3.6	+82 40	12.1
RS Urs. Maj.	34.4	+59 2	9.6	T Cephei	8.2	+68 5	10.1*d*
S Urs. Maj.	39.6	+61 38	8.8	S Cephei	36.5	+78 10	9.9
RV Virginis	13 2.8	—12 38	<12.0	S Lacertae	22 24.6	+39 48	9.2
RR Urs. Maj.	22.5	+62 55	<12.0	R Lacertae	38.8	+41 51	<12.0
R Hydrae	24.2	—22 46	4.1	V Cassiop.	23 7.4	+59 8	9.8 *i*
T Urs. Min.	32.6	+73 56	9.1	ST Androm.	33.8	+35 13	10.2
R Can. Ven.	44.6	+40 2	11.0	Z Cassiop.	39.7	+56 2	<13.0
U Urs. Min.	14 15.1	+67 15	8.8	RR Cassiop.	50.7	+53 8	10.4
S Bootis	19.5	+54 16	12.8	R Cassiop.	53.3	+50 50	13.5
R Camelop.	25.1	+84 17	10.7 *i*	Y Cassiop.	58.2	+55 7	12.0
S Cor. Bor.	15 17.3	+31 24	7.7	SV Androm.	59.2	+39 33	9.7*d*
S Urs. Min.	33.4	+78 58	11.1				

The letter *i* denotes that the light is increasing; the letter *d*, that the light is decreasing; the sign < that the variable is fainter than the appended magnitude.

The above magnitudes have been compiled at the Harvard College Observatory from observations made by the following observers:—H. C. Bancroft, T. C. H. Bouton, A. P. C. Craig, E. L. Forsyth, C. E. Furness, E. Gray, F. E. Hathorn, S. C. Hunter, M. W. Jacobs Jr., F. C. Leonard, O. Mach, C. Y. McAteer, W. T. Olcott, P. G. O'Reilley, F. E. Seagrave, H. M. Swartz, D. Todd, H. W. Vrooman, I. E. Woods, and A. S. Young.

Minima of Variable Stars of Short Period.

[Calculated by Myrtle L. Richmond, E. R. Peterson and S. N. Stearns at Goodsell Observatory.]

Given to the nearest hour in Greenwich mean time; to obtain eastern Standard time subtract 5^h; Central Standard 6^h, etc.

Star	R. A. 1900 h m	Decl. 1900 ° ′	Magnitude	Approx. Period d h	Greenwich mean times of minima in **May** 1913 d h	d h	d h	d h
SY Androm.	0 08.0	+43 09	9.5—13.0	34 21.9		3 1		
RT Sculptor	0 31.5	—26 13	9.6—10.5	0 12.3	2 14;	10 7;	17 23;	25 15
UU Androm.	38.5	+30 24	10.7—11.9	1 11.7	6 1;	13 11;	20 22;	28 8
U Cephei	0 53.4	+81 20	7.0— 9.0	2 11.8	3 1;	10 12;	18 0;	25 11
Z Persei	2 33.7	+41 46	9.4—12	3 01.4	3 10;	9 12;	21 18;	27 20
RY Persei	39.0	+47 43	8.0—10.3	6 20.7	3 10;	10 7;	24 0;	30 21
RZ Cassiop.	39.9	+69 13	6.4— 7.8	1 04.7	3 18;	10 22;	18 3;	25 7
ST Persei	53.7	+38 47	8.5—10.5	2 15.6	5 21;	13 20;	21 18;	29 17
RX Cassiop.	2 58.8	+67 11	8.6— 9.1	32 07.6		14 12		

Minima of Variable Stars of Short Period—Continued.

Star	R. A. 1900	Decl. 1900	Magnitude	Approx. Period	Greenwich mean times of minima in **May** 1913							
	h m	° ′		d h	d h	d h	d h	d h	d h	d h	d h	d h
Algol	3 01.7	+40 34	2.3— 3.5	2 20.8	2 5;	13 16;	25 5;	30 21				
RT Persei	16.7	+46 12	9.5—11.5	0 20.4	6 8;	13 3;	19 22;	26 17				
λ Tauri	55.1	+12 12	3.4— 4.5	3 22.9	5 23;	13 20;	21 18;	29 16				
RW Tauri	3 57.8	+27 51	7.1—<11	2 18.5	4 13;	12 20;	21 3;	29 11				
RV Persei	4 04.2	+33 59	9.5—11.0	1 23.4	0 15;	12 11;	24 7;	30 6				
RW Persei	4 13.3	+42 04	8.8—11.0	13 04.8		11 7;	24 12					
SZ Tauri	31.4	+18 20	7.2— 7.7	3 03.6	1 2;	7 9;	20 23;	27 6				
RS Cephei	4 48.6	+80 06	9.5—12.0	12 10.1		9 17;	22 3					
TT Aurigae	5 02.8	+39 27	7.8— 8.7	0 16.0	4 5;	10 21;	24 5;	30 20				
RY Aurigae	11.5	+38 13	10.7—11.7	2 17.5	2 14;	13 12;	24 10;	29 21				
RZ Aurigae	42.9	+31 40	10.6—13.3	3 00.3	6 22;	12 23;	25 0;	31 1				
SV Tauri	45.8	+28 05	9.4—11.0	2 04.0	4 11;	10 23;	23 23;	30 11				
SV Gemin.	5 54.6	+24 28	9.8—<11	4 00.2	8 15;	16 15;	24 15					
RW Gemin.	5 55.4	+23 08	9.5—11.0	2 20.8	4 24;	10 18;	22 5;	27 23				
U Columbae	6 11.2	−33 03	9.4—10.2	2 19.2	2 5;	13 10;	24 15;	30 5				
SX Gemin.	22.0	+20 37	10.8—11.5	1 08.8	1 17;	12 15;	23 14;	29 1				
RW Monoc.	6 49.4	− 7 28	9.8—10.5	0 21.5	3 17;	11 8;	18 23;	26 14				
RX Gemin.	43.6	+33 21	8.8— 9.6	12 05.0		10 22;	23 3;					
RU Monoc.	29.3	+ 8 54	9.0—10.8	1 21.7	7 6;	14 10;	21 14;	28 18				
R Can. Maj.	7 14.9	−16 12	5.8— 6.4	1 03.3	5 22;	11 14;	22 23;	28 15				
RY Gemin.	21.7	+15 52	8.9—<10	9 07.2	6 1;	15 8;	24 15					
Y Camelop.	27.6	+76 17	9.5—12	3 07.3	1 14;	8 5;	21 10;	28 1				
RR Puppis	43.5	−41 08	9.5—	6 10.3	1 11;	7 22;	20 18;	27 5				
V Puppis	7 55.4	−48 58	4.1— 5.8	1 10.9	5 17;	12 23;	20 6;	27 13				
X Carinae	8 29.1	−58 53	7.9— 8.7	0 13.0	4 23;	10 9;	21 5;	26 15				
S Cancri	38.2	+19 24	8.2—10	9 11.6	5 22;	15 10;	24 21					
S Antliae	27.9	−28 11	6.7— 7.8	0 07.8	1 15;	8 2;	21 1;	27 12				
S Velorum	28.5	−44 46	7.8— 9.1	5 22.4	4 15;	10 13;	22 10;	28 9				
Y Leonis	9 31.1	+26 41	9.3—11.2	1 16.5	4 10;	12 21;	21 7;	29 17				
RR Velorum	10 17.8	−41 36	10.0—10.9	1 20.5	1 4;	10 11;	19 17;	29 0				
SS Carinae	10 54.2	−61 23	12.2—12.8	3 07.0	2 14;	9 5;	22 10;	29 0				
ST Urs. Maj.	11 22.4	+45 44	6.7— 7.2	8 19.2	4 5;	13 0;	21 19;	30 14				
RW Urs. Maj.	35.4	+51 34	9.3—10.3	7 07.9	8 2;	15 10;	22 17;	30 1				
Z Draconis	11 40.6	+72 48	9.5—12.5	1 08.6	1 22;	8 17;	22 7;	29 2				
SS Centauri	13 07.2	−63 37	8.8—10.4	2 11.5	6 9;	13 19;	21 6;	28 16				
δ Librae	14 55·6	− 8 07	5. — 6.7	2 07.9	3 23;	10 22;	24 21;	31 21				
U Coronae	15 14.1	+32 01	7.6— 8.7	3 10.9	1 12;	8 9;	22 5;	29 3				
TW Draconis	32.4	+64 14	7.0— 8.9	2 19.4	3 13;	11 23;	20 10;	28 20				
114.1908 Librae	15 43.4	−64 14	9.3—11.5	0 18.4	3 19;	11 11;	19 2;	26 18				
SW Ophiuchi	16 11.1	− 6 44	9.2—10.0	2 10.7	7 12;	14 20;	22 4;	29 12				
SX Ophiuchi	12.6	− 6 25	10.5—11.2	2 01.5	1 1;	9 7;	17 13;	25 19				
R Arae	31.1	−56 48	6.7— 8.	4 10.2	4 22;	13 18;	22 15;	31 11				
TT Herculis	16 49.9	+17 00	8.9— 9.3	20 18.1	8 14;	19 15;	29 8					
TU Herculis	17 09.8	+30 50	9.5—12	2 06.4	2 4;	9 0;	22 14;	29 9				
U Ophiuchi	11.5	+ 1 19	6.0— 6.7	0 20.1	2 6;	10 15;	19 0;	27 10				
u Herculis	13.6	+33 12	5.1— 5.6	2 01.2	5 22;	12 2;	24 9;	30 13				
TX Herculis	15.4	+42 00	8.3— 9.0	1 00.7	2 5;	9 10;	23 20;	31 1				
RV Ophiuchi	29.8	+ 7 19	9. —<11	3 16.5	5 17;	13 2;	20 11;	27 20				
SZ Herculis	36.0	+33 01	9.5—10.3	0 19.6	6 4;	14 8;	22 12;	30 17				
TX Scorpii	48.6	−34 13	7.5— 8.2	0 22.6	1 0;	8 13;	23 15;	31 4				
Z Herculis	53.6	+15 09	7.1— 7.9	3 23.8	5 0;	14 0;	21 23;	29 23				
WX Sagittae	53.6	−17 24	9.2—10.8	2 36.6	4 6;	10 15;	23 10;	29 19				
WY Sagittae	17 54.9	−23 1	9.5—10.6	4 16.0	4 4;	13 12;	22 20;	27 12				
SX Draconis	18 03.0	+58 23	9.3—10.5	5 04.1	5 0;	15 8;	25 16;	30 20				
RS Sagittarii	11.0	−34 08	5.9— 6.3	2 10.0	5 4;	12 9;	19 15;	26 21				
V Serpentis	11.1	−15 34	9.5—11.1	3 10.9	5 11;	12 8;	29 6;	26 4				
RZ Scuti	21.1	− 9 15	7.4— 8.3	15 3.2		8 16;	23 19					
RZ Draconis	21.8	+58 50	9.5—10.2	0 13.2	6 9;	11 22;	22 22;	28 10				
RX Herculis	26.0	+12 32	7.0— 7.6	0 21.3	5 9;	14 6;	23 4					
SX Sagittarii	39.7	−30 36	8.6— 9.4	2 01.8	2 7;	8 12;	21 0;	27 5				

Minima of Variable Stars of Short Period.—Continued.

Star	R. A. 1900	Decl. 1900	Magnitude	Approx. Period	Greenwich mean time of minima in **May** 1913
	h m	° ′		d h	d h d h d h d h
RR Draconis	18 40.8	+62 34	8.5—<12	2 19.9	9 9; 17 21; 26 9
RS Scuti	43.7	−10 21	9.3—10.3	0 15.9	7 6; 13 21; 20 13; 27 4
β Lyrae	46.4	+33 15	3.4— 4.5	12 21.8	13 17; 26 15
U Scuti	18 48.9	−12 44	9.0— 9.8	0 22.9	3 17; 13 6; 22 20
RX Draconis	19 01.1	+58 35	9.3—10.2	1 21.5	1 17; 9 7; 16 20; 24 10
RV Lyrae	12.5	+32 15	11. —13	3 14.4	2 15; 9 20; 24 5; 31 10
RS Vulpec.	13.4	+22 16	6.9— 8.0	4 11.4	2 0; 10 23; 19 22; 28 21
U Sagittae	14.4	+19 26	6.7— 9.0	3 09.1	1 0; 7 18; 21 6; 28 1
Z Vulpec.	17.5	+25 23	7.3— 8.5	2 10.9	5 7; 12 15; 20 0; 27 9
TT Lyrae	24.3	+41 30	9.0—<11	5 05.8	2 9; 12 21; 22 9; 28 15
120.1907 Draconis	19 26.2	+68 44	9.3—10	1 15.1	1 3; 7 15; 20 16; 27 5
SY Cygni	19 42.7	+32 28	10 —12	6 00.2	6 7; 12 6; 24 7; 30 7
WW Cygni	20 00.6	+41 18	9.5—12.5	3 07.6	6 6; 12 21; 19 13; 26 4
SW Cygni	03.8	+46 01	9. —12	4 13.8	2 10; 11 14; 20 17; 29 21
VW Cygni	11.4	+34 12	9.5—11.5	8 10.3	1 11; 9 21; 18 8; 26 18
RW Capric.	12.2	−17 59	8.8—10.6	3 09.4	6 17; 13 12; 20 7; 27 1
UW Cygni	19.6	+42 55	10.5—13	3 10.8	5 17; 12 16; 19 14; 26 11
W Delphini	33.1	+17 56	9.5—11.5	4 19.4	6 14; 16 5; 25 19
RR Delphini	38.9	+13 35	10.5—11.8	4 14.4	6 8; 15 13; 24 18
Y Cygni	48.1	+34 17	7.1— 7.9	1 12.0	3 3; 10 15; 18 3; 25 14
WZ Cygni	49.3	+38 27	9.8—10.8	0 14.0	4 19; 10 16; 22 8; 28 4
RR Vulpec.	20 50.5	+27 32	9.6—11.0	5 01.2	5 8; 15 11; 25 13; 30 14
VV Cygni	21 02.3	+45 23	12.1—13.8	1 11.4	4 8; 11 17; 19 3; 26 12
AE Cygni	09.0	+30 20	10.8—11.4	0 23.3	3 8; 13 1; 22 17
UZ Cygni	55.2	+43 52	9. —11.5	31 07.3	18 4
RT Lacertae	21 57.4	+43 24	9.1—10.5	5 01.7	5 16; 15 19; 25 23; 31 1
RW Lacertae	22 40.6	+49 08	10.2—11.2	5 04.4	3 9; 13 18; 24 3; 29 7
X Lacertae	22 45.0	+55 54	8.2— 8.6	5 10.6	1 2; 11 23; 22 20; 28 7
TT Androm.	23 08.7	+45 36	10.5—11.3	2 18.3	6 5; 14 12; 22 19; 31 2
Y Piscium	29.3	+ 7 22	9.0—12.0	3 18.4	7 16; 15 4; 22 17; 30 6
TW Androm.	23 58.2	+32 17	8.6—11.5	4 02.9	2 14; 10 20; 19 2; 27 8

Maxima of Variable Stars of Short Period.

[Calculated by May E. Abbott, Hazel H. Barnard, Helen A. Orr, and Myrtle L. Richmond at Goodsell Observatory.]

Given to the nearest hour in Greenwich mean time. To obtain Eastern standard time subtract 5h; Central standard time 6h etc.

Star	R. A. 1900	Decl. 1900	Magnitude	Approx. Period	Greenwich mean times of maxima in **May** 1913.
	h m	° ′		d h	d h d h d h d h d h
SY Cassiop.	0 09.8	+57 52	9.3— 9.9	4 1.7	1 15; 9 18; 17 22; 26 1
RR Ceti	1 27.0	+ 0 50	8.3— 9.0	0 13.3	4 17; 12 11; 20 5; 27 23
RW Cassiop.	1 30.7	+57 15	8.9—11.0	14 19.2	1 7; 16 2; 30 22
V Arietis	2 09.6	+11 46	8.3— 9.0	0 23.8	4 19; 12 18; 20 16; 28 15
SU Cassiop.	2 43.0	+68 28	6.5— 7.0	1 22.8	7 1; 14 21; 22 16; 30 11
TU Persei	3 01.8	+52 49	11.4—12.2	0 14.6	1 16; 8 23; 23 12; 30 19
RW Camelop.	3 46.2	+58 21	8.2— 9.4	16 00.0	1 0; 17 0
SX Persei	4 10.2	+41 27	10.4—11.2	4 06.9	8 5; 16 18; 25 8
SV Persei	42.8	+42 07	8.8— 9.6	11 03.1	1 11; 12 14; 23 17
RX Aurigae	4 54.5	+39 49	7.2— 8.1	11 15.0	8 17; 20 8; 31 23
SX Aurigae	5 04.6	+42 02	8.0— 8.7	1 12.8	2 11; 10 2; 17 18; 25 10
SY Aurigae	05.5	+42 42	8.4— 9.5	10 03.3	3 5; 13 8; 23 12
Y Aurigae	21.6	+42 21	8.6— 9.6	3 20.6	1 9; 9 2; 16 19; 24 12
RZ Gemin.	5 56.6	+22 15	9.1—10.0	5 12.7	6 5; 11 17; 22 20; 28 7
RS Orionis	6 16.5	+14 43	7.8— 8.5	7 13.4	3 4; 10 17; 18 7; 25 20
T Monoc.	19.8	+ 7 08	5.7— 6.8	27 00.3	10 6
RZ Camelop.	23.7	+67 06	11.0—13.0	0 11.5	4 21; 12 2; 19 7; 26 12
W Gemin.	29.2	+15 24	6.8— 7.6	7 22.0	4 1; 11 23; 19 21; 27 19

Maxima of Variable Stars of Short Period.—Continued.

Star	R.A. 1900	Decl. 1900	Magnitude	Approx. Period	Greenwich mean times of maxima in May 1913.
	h m	° ′		d h	d h d h d h d h
ζ Gemin.	6 58.2	+20 43	3.7— 4.5	10 03.7	2 18; 12 21; 23 1
RU Camelop.	7 10.9	+69 51	8.5— 9.8	22 06.5	3 13; 25 19
RR Gemin.	7 15.2	+31 04	10.0—11.5	0 09.5	2 7; 10 6; 18 5; 26 3
V Carinae	8 26.7	−59 47	7.2— 8.0	6 16.7	6 3; 12 20; 19 12; 26 5
T Velorum	8 34.4	−47 01	7.5— 8.5	4 15.3	5 23; 15 5; 24 12
W Carinae	9 19.2	−55 32	7.5— 8.5	4 08.9	7 5; 15 22; 24 16
W Ursae Maj.	9 36.7	+56 24	7.9— 8.6	0 04.0	4 16; 11 8; 24 16; 31 8
RR Leonis	10 02.1	+24 03	9.1—10.1	0 10.9	5 15; 12 10; 19 5; 26 0
SW Draconis	11 32.2	+67 53	8.9— 9.6	0 16.0	3 23; 10 13; 23 18; 30 9
S Muscae	12 07.4	−69 36	6.5— 7.3	9 15.8	8 7; 17 23; 27 15
SU Draconis	12.8	+70 04	8.8— 9.6	0 13.7	1 1; 9 1; 17 0; 24 23
T Crucis	15.9	−61 44	6.8— 7.6	6 17.6	7 17; 14 10; 21 4; 27 22
R Crucis	18.1	−61 04	6.8— 8.0	5 19.8	3 3; 8 23; 20 15; 26 11
S Crucis	48.4	−57 53	6.6— 7.8	4 16.6	2 8; 11 17; 21 2; 30 11
RZ Centauri	12 55.6	−64 05	8.5— 8.9	1 21.0	5 18; 13 6; 20 18; 28 6
W Virginis	13 20.9	− 2 52	8·7—10.4	17 06.5	5 0; 22 7
RV Ursae Maj.	13 29.4	+54 31	9.2— 9.9	0 11.2	2 11; 9 12; 23 13; 30 13
ST Virginis	14 22.5	− 0 27	10.3—11.4	0 09.9	3 23; 12 4; 20 9; 28 14
V Centauri	25.4	−56 27	6.4— 7.8	5 11.9	5 4; 10 15; 21 15; 27 3
RS Bootis	29.3	+32 11	8.9—10.0	0 09.1	8 3; 15 16; 23 5; 30 18
RU Bootis	14 41.5	+23 44	12.8—14.3	0 11.9	1 10; 8 20; 16 6; 23 16
R Triang. Austr.	15 10.8	−66 08	6.7— 7.4	3 09.3	1 18; 8 13; 21 2; 27 21
S Triang. Austr.	15 52.2	−63 29	6.4— 7.4	6 07.8	4 5; 10 12; 23 4; 29 12
S Normae	16 10.6	−57 39	6.5— 7.4	9 18.1	7 23; 17 17; 27 11
RW Draconis	33.7	+58 03	9.6—10.8	0 10.6	8 14; 17 11; 26 7
RV Scorpii	16 51.8	−33 27	6.7— 7.4	6 01.5	6 0; 12 1; 24 4; 30 6
X Sagittarii	17 41.3	−27 48	4.4— 5.0	7 00.3	5 3; 12 4; 19 4; 26 4
Y Ophiuchi	47.3	− 6 07	6.1— 6.5	17 02.9	3 5; 20 7
W Sagittarii	17 58.6	−29 35	4.3— 5.1	7 14.3	3 18; 11 8; 18 22; 26 12
Y Sagittarii	18 15.5	−18 54	5.4— 6.2	5 18.6	3 18; 9 12; 21 0; 26 20
U Sagittarii	18 26.0	−19 12	6.5— 7.3	6 17.9	4 11; 11 5; 24 17; 31 11
Y Scuti	32.6	− 8 27	8.7— 9.2	10 08.3	9 8; 19 16; 30 0
Y Lyrae	34.2	+43 52	11.3—12.3	0 12.1	4 9; 10 10; 22 11; 28 12
RZ Lyrae	39.9	+32 42	9.9—11.2	0 12.3	4 1; 10 4; 22 10; 28 14
RT Scuti	44.1	−10 30	9.1— 9.7	0 11.9	6 1; 12 0; 23 21; 29 20
κ Pavonis	18 46.6	−67 22	3.8— 5.2	9 02.2	5 9; 14 12; 23 14
U Aquilae	19 24.0	− 7 15	6.2— 6.9	7 00.6	3 9; 10 9; 24 10; 31 11
XZ Cygni	30.4	+56 10	8.7— 9.3	0 11.2	7 13; 14 12; 21 12; 28 12
U Vulpec.	32.2	+20 07	6.9— 7.6	7 23.5	2 1; 10 0; 18 0; 25 23
SU Cygni	40.8	+29 01	6.6— 7.4	3 20.3	6 8; 14 0; 21 17; 29 10
η Aquilae	47.4	+ 0 45	3.7— 4.5	7 04.2	5 18; 12 22; 20 2; 27 6
S Sagittae	51.5	+16 22	5.6— 6.4	8 09.2	1 23; 10 8; 18 18; 27 3
X Vulpec.	19 53.3	+26 17	9.5—10.5	6 07.7	2 14; 8 22; 21 13; 27 21
XX Cygni	20 01.3	+58 40	10.5—11.5	0 03.2	2 6; 9 0; 22 12; 29 6
X Cygni	39.5	+35 14	6.0— 7.0	16 09.3	3 3; 19 12
T Vulpec.	47.2	+27 52	5.5— 6.5	4 10.5	2 15; 12 13; 21 9; 30 6
WY Cygni	52.3	+30 03	9.5—10.3	0 13.5	2 9; 9 3; 22 14; 29 7
RV Capric.	55.9	−15 37	9.2—10.1	0 10.7	3 23; 10 16; 24 2; 30 19
TX Cygni	20 56.4	+42 12	8.5— 9.7	14 17.4	11 19; 26 1 2
VY Cygni	21 00.4	+39 34	8.9— 9.5	7 20.6	3 21; 11 18; 19 15; 27 11
VZ Cygni	21 47.7	+42 40	8.4— 9.2	4 20.7	4 12; 14 5; 23 22; 28 19
Y Lacertae	22 05.2	+50 33	9.1— 9.6	4 07.8	2 22; 11 14; 20 5; 28 21
δ Cephei	25.5	+57 54	3.7— 4.6	5 08.8	2 23; 13 17; 24 10; 29 19
Z Lacertae	36.9	+56 18	8.2— 9.0	10 21.1	1 20; 12 17; 23 14
RR Lacertae	37.5	+55 55	8.5— 9.2	6 10.1	2 19; 9 5; 22 1; 28 12
V Lacertae	22 44.5	+55 48	8.2— 8.9	4 23.6	2 13; 12 13; 22 12; 27 11
SW Cassiop.	23 03.7	+58 11	9.2— 9.7	5 10.6	4 17; 15 14; 26 12; 31 22
RS Cassiop.	32.6	+61 52	9.1—10.0	6 07.1	1 1; 7 8; 19 23; 26 6
RY Cassiop.	47.2	+58 11	9.2—10.0	12 03.4	4 9; 16 13; 28 16
U Pegasi	23 52.9	+15 24	9.3— 9.9	0 04.5	3 11; 10 23; 18 11; 25 23

Variable Star Observations, made by Šafařík, and discussed by L. Pračka are published in the *Astronomische Nachrichten*, No. 4626. These observations were made between the years 1880 and 1890 inclusive, and give the dates at which maxima and minima of the several stars occurred. The estimated magnitudes of the stars also are given for these times. Sixteen stars are discussed.

RS Geminorum.—According to the elements of this star given by M. Hartwig, in his catalogue and ephemerides of variable stars for 1912, this star should have been at a maximum on May 8, 1912. At that time the variable on the contrary was at a minimum. On the other hand it was relatively bright on February 26, a date for a predicted minimum. Because of this discordance I have determined new elements of this star. A graphical discussion of my observations leads to the following elements;

$$\text{Max.} = \text{J.D. } 2416915 + 151^{d}.\ \text{E.}$$

This period is about six days longer than that adopted hitherto. (M. Luizet in *A.N.* No. 4626).

New Elements of RW Tauri.—This star of the Algol type, which varies over a large range, is assigned new elements by K. Graff in *A.N.* No. 4633 as follows:

$$\text{Min.} = \text{J.D. } 2417198.4094 \text{ (G.M.T.)} + 2^{d}.768904 \text{ E.}$$

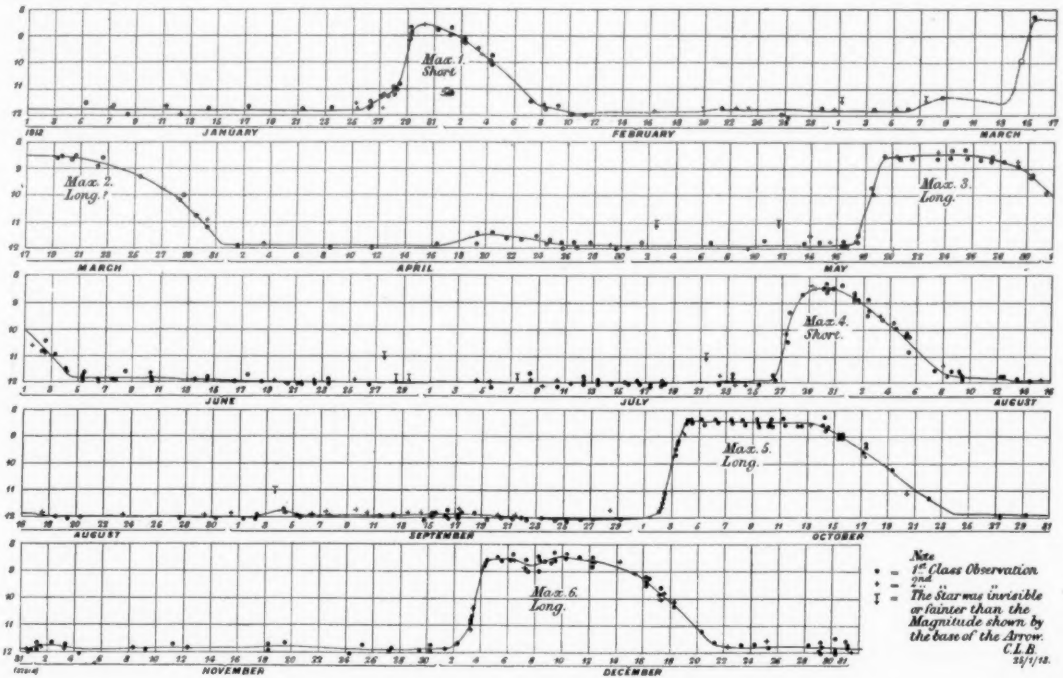
The writer sees in the character of the light-curve very strong evidence that in this system a smaller bright star is eclipsed almost centrally by a larger and relatively dark component.

Light Curve of SS Cygni.—The accompanying diagram of the light-curve of SS Cygni, taken from the *Journal of the British Astronomical Association* for January 1913, will be of interest to compare with the one which we published last year (P.A. Vol. XX, p. 321). The many observations made last year by the members of our own Variable Star Association ought to be plotted in a similar manner.

Variable Star 6.1911 Trianguli. – Observations made in the spring of the year 1911 show that this star belongs among the short period variables of the δ Cephei class. Using an approximate period, from a number of photographic plates taken in 1907-1911 the more accurate period and elements were found to be the following:

$$\text{Max.} = \text{J. D. } 2419100.227 \text{ (G.M.T.)} + 0^{d}.447250 \text{ E}$$
$$\text{or 1911 Mar. 4 } 5^{h}\ 27^{m} \text{ “ } + 10^{h}\ 44^{m}\ 2^{s}.4 \text{ E}$$

The brightness at maxinum is $11^{m}.1$ and at minimum $12^{m}.0$. The rise from minimum to maximum is accomplished very rapidly and requires scarcely more than 80 minutes. (S. Blažko in *A. N.* 4626).



LIGHT CURVE OF SS CYGNI FROM THE BRITISH OBSERVATIONS DURING 1912.

Variable Star 1.1913 Geminorum.—This star was announced in *A.N.* 4626 by Frederic C. Leonard as being suspected of variability. In *A.N.* 4632, notes by F. Alker and E. Jost fail to confirm the variation in this star.

Variable Star 2.1913 Cassiopeiae.—This star is announced by C. R. d'Esterre in *A.N.* No. 4632. It was discovered by an examination of plates taken between Aug. 9, 1911 and Jan. 5, 1913. Its variability was later verified visually. It is in a rather dense region of the Milky Way and may have been overlooked up to this time because of the numerous stars in that region.

Variable Star 3.1913 Aurigae.—On February 1, Mme. Ceraski found a new variable whose approximate position for 1900 is

$$\alpha = 4^h\ 45^m\ 22^s \qquad \delta = +\ 30^\circ\ 37'.$$

A discussion of 24 plates obtained between 1895 and 1912 shows that this star varies between the limits $9^m.7$ and $11^m.3$ approximately. (*A.N.* No. 4632.)

Observations of Nova (2) Geminorum.—Herewith are given my observations of Nova (2) Geminorum continued from those published in the March, 1913, issue of this journal. Telescope used, 4-inch equatorial refractor.

OBSERVATIONS OF NOVA (2) GEMINORUM

1913 Feb. 11–Mar. 11.

Date	Mag.	Color	Comparison Stars
Feb. 11	8.3	Very light bluish green	BD.+32° 1442 and 1447
Feb. 12	8.3	Very light bluish green	BD.+32° 1434, 1442, 1447
Feb. 13	8.3	Very light bluish green	BD.+32° 1434, 1442, 1447
Feb. 14	8.4	Very light bluish green	BD.+32° 1434, 1442, 1447
Feb. 18	8.3	Very light bluish green	BD.+32° 1442 and 1447
Mar. 4	8.3	Very light bluish green	BD.+32° 1442 and 1447
Mar. 6	8.3	Very light bluish green	BD.+32° 1442 and 1447
Mar. 8	8.4	Very light bluish green	BD.+32° 1442 and 1447
Mar. 11	8.4	Very light bluish green	BD.+32° 1442 and 1447

The small number of observations obtained during the month just completed is due mainly to the excessive cloudiness which has prevailed a large part of the time; for instance, between Feb. 18 and Mar. 4, it was cloudy here almost every night.

Throughout this entire set of observations, as may be seen from the above table, in striking contrast to its remarkably active condition last month (see my article in March, 1913, P. A., pp. 168-169), the Nova has remained practically the same both in point of magnitude and color. It has been of either magnitude 8.3 or 8.4 during the whole month, and its color has been absolutely unchanged. It appears, therefore, as though the star were again experiencing a period of quiescence, especially after its unusual fluctuations in the course of the preceding weeks.

The Nova is certainly most interesting, and well worth all of the attention that observers can devote to it. Its almost endless cycle of variations, its unexpected activity and the surprising phenomena that it has manifested during the one year in which it has been under observation, surely cannot fail to increase our knowledge of that wonderful and most mysterious class of suns,—the "temporary" or "new" stars.

FREDERICK C. LEONARD.

1338 Madison Park, Chicago, Ill.,
1913, March 12.

Rise of Betelgeux.—I can corroborate Mr. F. E. Seagrave's observations, (P. A. 203, p. 178), relative to the rise of Betelgeux (α Orionis). My records of this star show that it began to rise, after a fairly considerable period of relative faintness, on February 8, when I estimated it at magnitude 0.30. It has been unusually bright ever since that date, and from February 12, according to my estimates, it has been of approximately the 0.25 magnitude, or half way between Capella (magnitude 0.2) and Rigel (magnitude 0.3) in brilliancy. I am also giving much attention to this star, as it has been on my regular observing list of variable stars both last season and this.

FREDERICK C. LEONARD.

1913, March 12.

COMET AND ASTEROID NOTES.

New Comet 1912 *d*.—In *A. N.* 4634 Mr. G. F. Dodwell of Adelaide, Australia, gives an account of the discovery of a comet on the morning of Dec. 31, 1912, by Mr. B. Lowe, of Laura, Australia. Mr. Lowe observed the comet on the mornings of January 3, 5, 6 and 9, but did not determine its position. The announcement was not received at Adelaide until Jan. 7, and owing to an error in the altitude given for the new comet search for it on the mornings of Jan. 8 and 11 was fruitless. A diagram received Jan. 15 indicated that the comet's path was southeastward through Virgo, Hydra and Lupus, but its motion carried it into the morning twilight, so that so far as known it has not been detected at any observatory. The comet is described by Mr. Lowe as "invisible to the naked eye or with field glasses, but appearing distinct, although small, in a 3-inch telescope." The following are rough positions from a chart by Mr. Lowe:

Greenwich Mean Time	R. A.	Decl.
	h m	° ′
1912 Dec. 30 5 30	13 18	— 6 30
1913 Jan. 2 5 30	13 38	—17 40
4 5 30	14 07	—25 40
5 5 30	14 30	—29 50

On the morning of Jan. 9 the comet is stated to have been "near the Scorpion". It is to be hoped that there may be found photographs of the region passed by the comet, taken on some of these or earlier dates, which may reveal the presence of the stranger and so furnish data for the determination of its orbit.

Independent Discovery of Comet 1912 *a* **(Gale).**—In the *Journal of the British Astronomical Association* for January, 1913, are given memoranda which show that Mr. J. F. Skjellerup, of Rosebank, near Capetown, Africa, discovered Comet 1912 *a* three days after it had been found by Gale in Australia. Mr. Skjellerup was sweeping the sky with Zeiss binoculars on the evening of September 11, when he noticed an unknown nebulous object near *g* and *k* Centauri. He verified his discovery as that of a comet on September 12.

It is reported that this comet was discovered by Mr. Lowe, mentioned above, prior to its discovery by Gale, but no immediate announcement was made, and the nature of the observations was not such as to affect Gale's title to priority.

New Elements of Comet 1906 IV (Kopff.)—In *A. N.* 4633 Mr. G. Zappa, of Naples, gives the following elements, which he says are almost definitive, of the periodic comet 1906 IV (Kopff):

Epoch 1906 August 27.5 Berlin mean time.

$$\begin{aligned} M &= 17^\circ\ 29'\ 43''.4 \\ \omega &= 19\ 49\ 42\ .2 \\ \Omega &= 263\ 39\ 13\ .1 \\ i &= 8\ 42\ 45\ .7 \\ \phi &= 31\ 4\ 38\ .0 \\ \mu &= 539''.150 \\ \log a &= 0.545531 \end{aligned} \quad \left.\begin{matrix} \\ \\ \\ \\ \end{matrix}\right\} 1906.0$$

Period = 6.581 years.

According to these elements the comet should have been at perihelion on November 30, 1912, but in quite unfavorable position for observation. It will be much more favorably situated at its next return in the summer of 1919.

Definitive Elements of Comet 1899 V (Giacobini).—In *A. N.* 4631 Mr. Kr. Lous, of Christiana, gives the following definitive elements of the comet 1899 V discovered by Giacobini at Nice, based upon all the available observations, extending over the period from October 1 to December 23, 1899.

$$\begin{aligned} T &= 1899\ \text{Sept.}\ 14.93750\ \text{Berlin mean time} \\ \omega &= 10^\circ\ 47'\ 11''.8 \\ \Omega &= 272\ 13\ 25\ .5 \\ i &= 76\ 56\ 32\ .2 \\ \log q &= 0.251842 \end{aligned} \quad \left.\begin{matrix} \\ \\ \\ \\ \end{matrix}\right\} 1900.0$$

Ephemeris of Planet (52) Europa.

For Paris Midnight.

1913		α 1913.0 h m s	δ 1913.0 ° ′	log r	log Δ
April	4	13 46 20	+0 6.7	0.4898	0.3241
	8	43 29	0 28.3	0.4904	0.3233
	12	40 32	0 49.0	0.4910	0.3235
	8 16	37 34	1 8.4	0.4917	0.3245
	20	34 38	1 26.3	0.4923	0.3265
	24	31 46	1 42.2	0.4929	0.3294
	28	29 0	1 56.2	0.4935	0.3331
May	2	26 23	2 8.0	0.4941	0.3376
	6	23 58	2 17.2	0.4947	0.3430
	10	21 48	2 24.0	0.4954	0.3489
	14	19 54	2 28.3	0.4960	0.3556
	18	18 16	2 30.1	0.4966	0.3628
	22	16 55	2 29.4	0.4972	0.3703
	26	15 53	2 26.2	0.4978	0.3782
	30	15 9	2 20.8	0.4984	0.3866
June	3	14 44	2 13.1	0.4989	0.3951
	7	13 14 39	+2 3.4	0.4995	0.4036

Brightness at opposition $10^m.3$.

The Asteroid (52) Europa.—In *A. N.* 4632 Mr. Henri Blondel gives an ephemeris for the present opposition of the asteroid (52) Europa. As this little planet will be of about the tenth magnitude at opposition, it will be within reach of amateurs with three and four inch telescopes, and so we give a portion of the ephemeris extending from April 4 to June 7. In order to aid in picking up the asteroid we have prepared the accompanying chart, showing the stars of Argelander's *Durchmusterung* which lie along the path of the planet. The stars shown upon the chart go down only to magnitude 9.5, so the observer, after identifying the field, will need to fill in the fainter stars which are visible with his telescope, and note which one moves from night to night.

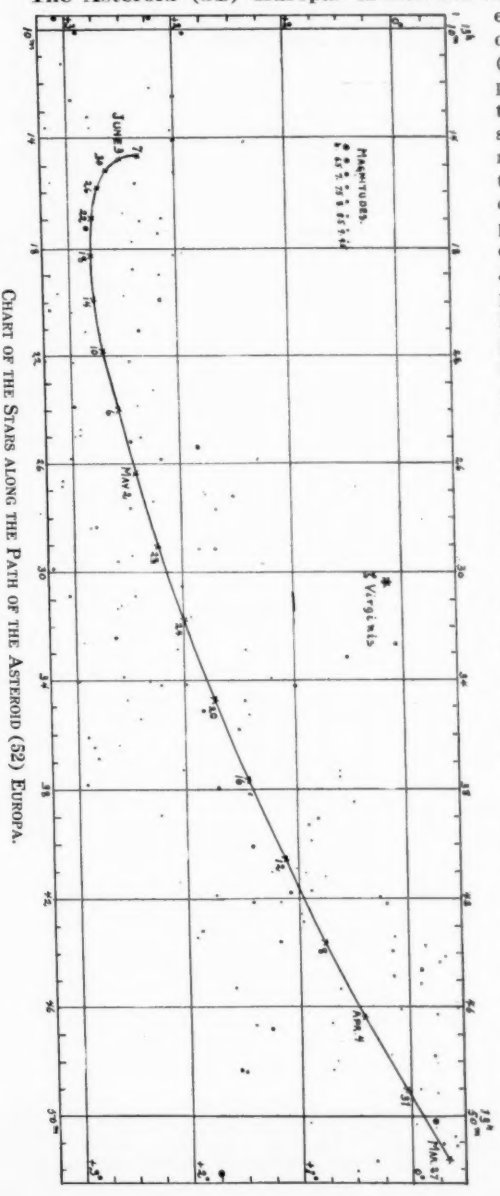


CHART OF THE STARS ALONG THE PATH OF THE ASTEROID (52) EUROPA.

For those who are provided with photographic telescopes the chart will be of some value in indicating the guide stars which are available along the planet's route. This is a rather sparse region of the sky and the stars bright enough to use for guiding the telescope during a long exposure are few and far between. The best opportunities for photographs appear to be on March 29, April 11, 13, 16, 20, May 4 and 21.

NOTES FOR OBSERVERS.

Monthly Report of the American Association of Variable Star Observers, Feb.-Mar., 1913.—Bad weather and illness have combined to cut down the length of the individual observing lists this month, consequently this report in number of observations is hardly up to our standard.

Dr. Gray came to the rescue with 161 observations of 75 variables, a remarkable record, and one to be proud of. He observed on nineteen nights in February, which gives an idea of weather conditions on the Pacific coast in mid-winter. In the east we are fortunate if we get ten good observing nights during the winter months. Messrs. Bancroft and Lacchini each sent in 101 observations.

Mr. F. W. Waters of Coburg, Australia, has lately joined the Association. Mr. Waters observes with a three-inch refractor, and we hope through him to cover some of the neglected southern variables.

Dr. Hartwig calculated a maximum (8.2) for 032043 Y Persei for February 20. A maximum of about 8.6 was observed close to that date.

A calculated maximum for 043274 X Camelopard. (7.5) on February 8 was confirmed by the observations.

February 9 was the calculated date for the maximum of 094211 R Leonis (5.0). On approximately this date the variable was about seventh magnitude and waxing.

The variable 233335 ST Andromedae according to calculations was at maximum February 6. Observations indicate that this star was about the tenth magnitude and waning on said date.

The calculated maximum on February 12 in the case of the variable 235939 SV Andromedae failed of confirmation by observation, as the variable appears to have been about ninth magnitude on that date and waning.

On the whole the observations this month were in closer agreement than for some months past. There are many cases of identical estimates on the same dates. Observers must not be disturbed by the discrepancies apparent many times in a comparison of the observations, especially in the case of the red stars, as many factors tend to prevent a close agreement in the estimates of a number of observers. It must always be remembered that the *mean* light curve is the result of interest derived from the contributed data.

The quality of the observations is entirely dependent on the experience of the observers, and as we have only started on this work, a close agreement in the estimates is hardly to be expected; but, as the hand of the artist is trained by constant practice, so it is with the eye of the observer, and time, and persistent efforts, are bound to produce the results that should be satisfactory to those who place a value on the data we are contributing. In the ten days following January 25, four observers noted an increase of approximately half a magnitude in 064932 Nova Geminorum.

The secretary is grateful to Mr. Bancroft for calling attention to the work of the Association in his interesting article in the March issue of "POPULAR ASTRONOMY". He must however correct the statement that he is Director of the work. The Director of the Association is Professor E. C. Pickering, Director of the Harvard College Observatory, to whom we are indebted for our charts, and to whom we send reports of our individual observations.

Subsequent to March 25 074922 U Geminorum should be observed by all at every opportunity.

VARIABLE STAR OBSERVATIONS Feb.–Mar., 1913.

001755
T Cassiop.

Mo.	Day	Est.	Obs.
2	10	11.1	J
	23	11.2	J
	24	11.2	Y
	25	11.2	Ba
3	2	11.2	J
	5	11.2	Ba
	6	11.5	J

001838
R Androm.

2	1	7.2	G
	9	7.0	G
	10	6.8	L
	15	6.9	L
	16	6.8	L
	23	6.9	L
	24	7.0	L
	24	7.2	V

004132
RW Androm.

2	10	8.6	J
	23	8.3	J
	24	8.2	J
3	2	8.2	J
	5	8.3	J
	6	8.2	J

004958
W Cassiop.

2	10	10.4	J
	23	10.0	J
3	2	9.8	J
	6	9.8	J

012502
R Piscium

2	8	8.5	Y
	24	8.6	Y

013238
RU Androm.

2	10	11.0	J
	23	10.8	J
	24	10.7	J
3	2	10.9	J
	6	10.4	J

014958
X Cassiop.

2	8	10.5	Y
	24	10.8	Y

015354
U Persei

	9	9.0	O

021024
R Arietis

Mo.	Day	Est.	Obs.
2	6	10.2	G
	15	8.5	G
	25	8.6	S
	25	8.0	Ba
	27	8.7	G
3	3	8.0	Ba
	5	8.0	O
	8	8.0	O

021143 a
W Androm.

2	12	10.0	F
	28	11.3	F

021258
T Persei

2	24	8.7	B
	24	8.7	Ba
3	5	8.7	Bu

021403
o Ceti

1	27	8.0	L
2	1	7.8	G
	3	7.5	Gi
	3	7.6	L
	6	7.7	G
	7	7.3	V
	8	7.6	Ha
	9	7.1	L
	10	7.7	G
	12	7.2	Hu
	12	7.0	F
	15	6.9	L
	16	7.1	L
	23	5.9	L
	24	5.8	L
	24	6.0	Hu
	27	6.3	G
	28	6.0	F
3	5	5.5	O

021558
S Persei

2	10	8.2	B
	24	8.1	B
	24	8.1	Ba
3	5	8.0	B
	5	8.2	Ba

022000
R Ceti

2	27	8.6	G

023133
R Trianguli

2	8	8.3	Y
	24	7.5	Y
	27	7.2	G
3	2	6.8	G
	5	7.0	Y
	9	6.7	O

024356
W Persei

Mo.	Day	Est.	Obs.
2	6	9.2	Le
	7	9.3	Le
	8	9.5	Le
	9	9.4	Le
	11	9.4	Le
	12	9.5	Le
	13	9.4	Le
	14	9.3	Le
	24	9.2	Hu
	24	9.0	V
	27	9.6	G
3	4	9.3	Le
	5	9.7	O
	6	9.2	Le

030514
U Arietis

2	13	8.6	Y
	24	8.6	Y
3	5	8.8	O
	5	8.8	Y

031401
X Ceti

2	12	9.9	F
	28	11.4	F

032043
Y Persei

2	10	8.7	B
	10	8.5	Ba
	14	8.6	Ba
	18	8.6	Ba
	24	8.5	Hu
	24	8.7	B
	25	9.4	Ba
	27	9.5	G
	28	9.6	Ba
	28	9.6	F
3	5	9.2	B
	5	9.6	Ba
	9	10.0	O

042215
W Tauri

2	23	10.8	O
	24	10.2	Y
	28	10.4	G
3	5	10.0	O
	5	9.9	Y
	8	10.0	O
	9	10.0	O

043065
T Camelop.

2	24	8.8	Y

043208
RX Tauri

2	3	12.1	Gi
	9	11.9	Gi

043274
X Camelop.

Mo.	Day	Est.	Obs.
2	8	7.6	Y
	9	7.9	G
	9	7.5	O
	11	7.8	G
	12	8.0	O
	13	7.7	Y
	23	7.7	O
	24	8.0	Y
3	5	8.1	O
	8	8.3	O
	9	8.4	O

045307
R Orionis

2	13	9.4	Y
	25	9.3	Y
3	5	9.7	Y
	9	9.5	O

045514
R Leporis

1	27	8.6	L
2	1	7.4	F
	2	7.4	G
	3	8.0	Gi
	4	7.5	F
	6	7.4	G
	6	8.1	Le
	7	7.5	Le
	8	7.6	Le
	8	7.2	Ba
	8	7.5	Ha
	9	8.5	L
	9	7.4	G
	9	8.1	Le
	10	7.1	B
	11	7.7	Le
	12	7.5	F
	12	8.0	Le
	13	7.6	Le
	13	8.0	L
	14	7.1	Ba
	14	7.6	Le
	15	7.7	Gi
	15	8.2	L
	15	7.0	B
	15	7.3	G
	16	7.2	Ha
	16	8.4	L
	19	7.1	B
	19	7.3	G
	22	6.9	Ba
	23	8.2	L
	24	7.3	G
	24	7.8	L
	24	7.7	V
	24	7.3	Ha
	25	7.2	B
	28	6.9	Ba

R Leporis

Mo.	Day	Est.	Obs.
2	28	7.3	F
3	3	7.4	B
	3	6.9	Ba
	6	8.3	Le

050003
V Orionis

2	1	9.4	G
	10	8.8	G?
	13	10.1	Y
	25	10.1	Y
3	2	9.6	G
	5	10.4	Y

050022
T Leporis

2	11	11.2	G
	27	11.6	G

050953
R Aurigae

2	4	10.0	F
	13	10.2	Y
	23	11.0	J
	24	10.5	B
3	2	11.3	J
	5	11.0	Y
	5	10.7	B

052034
S Aurigae

2	4	9.2	F
	13	8.9	Y
	25	8.9	Y
	27	9.2	G

053068
S Camelop.

2	8	8.1	Y
	24	8.4	Y

053531
U Aurigae

2	25	11.8	Y
3	5	11.0	Y

054319
SU Tauri

2	24	9.5	Y

054920
U Orionis

2	3	11.6	Gi
	12	11.2	Hu
	24	11.0	Hu

054974
V Camelop.

2	12	11.0	O
	23	9.7	O
3	5	9.5	O
	8	9.6	O
	9	9.6	O

VARIABLE STAR OBSERVATIONS Feb.–Mar., 1913.—Continued.

055353
Z Aurigae

Mo.	Day	Est.	Obs.
2	8	9.6	Y
	25	9.4	Y

060547
SS Aurigae

Mo.	Day	Est.	Obs.
2	25	11.8	Y

061702
V Monoc.

Mo.	Day	Est.	Obs.
2	9	9.2	G
	11	9.2	G
	19	9.8	G
	26	8.7	G
3	2	8.1	V
	9	7.6	O

062808
Z Monoc.

Mo.	Day	Est.	Obs.
2	26	8.4	G

063159
U Lyncis

Mo.	Day	Est.	Obs.
2	8	10.4	Ba
	10	10.3	Ba
	14	10.2	Ba
	18	9.9	Ba
	24	10.2	Ba
	28	10.3	Ba
3	3	10.7	Ba
	5	10.7	Ba

063308
R Monoc.

Mo.	Day	Est.	Obs.
2	10	9.0	G

064932
NOVA GEMIN. 2

Mo.	Day	Est.	Obs.
2	2	7.9	G
	3	7.6	L
	6	7.2	G
	7	7.8	V
	8	7.9	C
	8	8.0	M
	9	8.7	Gi
	9	8.1	G
	9	8.2	L
	10	8.1	G
	11	8.4	L
	12	8.1	O
	14	8.7	Y
	15	8.8	Gi
	15	8.0	L
	16	7.6	L
	23	8.4	L
	24	8.5	Y
	24	8.3	G
	24	8.3	V
	24	8.2	L
	25	8.3	M
	28	8.2	G
3	2	8.3	M
	5	8.2	M

065208
X Monoc.

Mo.	Day	Est.	Obs.
2	9	9.0	G
	10	8.5	G
	11	8.5	G
	19	7.5	G
	24	8.0	G
	26	7.7	G
3	2	7.6	G

065355
R Lyncis

Mo.	Day	Est.	Obs.
2	8	8.5	Y
	10	8.1	Ba
	14	7.7	Ba
	18	8.0	Ba
	24	8.5	J
	24	8.2	Ba
	24	8.4	Y
	28	8.2	Ba
3	2	9.0	J
	3	8.4	Ba
	5	8.9	J
	5	8.5	Ba
	5	8.6	Y

070122 a
R Geminorum.

Mo.	Day	Est.	Obs.
2	12	11.6	Hu
	14	9.1	G
	24	11.6	Hu

070310
R Can. Min.

Mo.	Day	Est.	Obs.
2	13	9.3	L
	23	9.5	O
	27	9.6	G
3	2	10.2	V
	2	10.0	G
	5	10.1	O

071044
L^2 Puppis

Mo.	Day	Est.	Obs.
2	17	3.5	G
	28	3.5	F

072708
S Can. Min.

Mo.	Day	Est.	Obs.
2	1	9.3	F
	1	8.9	G
	2	8.8	G
	4	8.7	F
	6	8.8	G
	8	8.9	Ha
	8	8.8	Ba
	8	8.9	Ma
	9	8.7	G
	9	8.7	L
	9	8.8	Ha
	10	8.6	B
	11	8.6	G

S Can. Min.

Mo.	Day	Est.	Obs.
2	12	8.5	F
	12	8.7	O
	13	8.5	Ma
	13	8.5	L
	16	8.5	Ha
	16	8.5	L
	23	8.3	L
	23	8.3	O
	24	8.4	G
	24	8.2	L
	24	8.1	Ba
	24	8.3	Ha
	25	8.3	M
	25	7.9	B
	27	8.1	G
	28	8.4	F
3	1	8.0	Ma
	2	8.4	Ha
	2	8.1	M
	2	8.0	G
	3	7.8	B
	3	7.8	Ba
	5	8.1	O
	5	8.1	M
	5	7.7	Ba
	8	8.0	O

072820 b
Z Puppis

Mo.	Day	Est.	Obs.
2	11	10.1	G

073508
U Can. Min.

Mo.	Day	Est.	Obs.
2	8	12.6	Y
	10	12.4	Ba
	24	13.0	Y
3	5	13.0	Y

074922
U Geminorum

Mo.	Day	Est.	Obs.
2	12	11.6	Hu
	24	11.6	Hu
3	2	13.8	J

075548
V Puppis

Mo.	Day	Est.	Obs.
2	28	5.0	F

080322
RU Puppis

Mo.	Day	Est.	Obs.
2	12	8.2	G

081112
R Cancri

Mo.	Day	Est.	Obs.
2	10	10.6	L
	12	9.4	Hu
	13	10.5	L
	14	10.3	Ba
	24	9.4	Hu
	28	9.9	Ba

R Cancri

Mo.	Day	Est.	Obs.
3	2	10.0	V
	5	9.5	O
	5	9.4	Ba
	9	9.5	O

081617
V Cancri

Mo.	Day	Est.	Obs.
2	9	7.9	Gi
	11	8.7	G
3	2	8.3	G
	5	7.8	O

081733
T Lyncis

Mo.	Day	Est.	Obs.
2	9	11.2	G
	28	11.0	G
3	4	9.2	G

082405
RT Hydrae

Mo.	Day	Est.	Obs.
2	10	9.0	L
	12	8.8	G
	25	9.0	Ba
3	2	8.8	V
	5	9.1	O
	5	8.6	Ba
	8	8.9	O

084803
S Hydrae

Mo.	Day	Est.	Obs.
2	23	8.0	O
	24	8.2	Hu
	25	8.0	B
	25	8.0	Ba
	26	9.2	G
3	3	8.0	B
	5	8.0	O
	5	8.2	Ba
	8	8.0	O

085120
T Cancri

Mo.	Day	Est.	Obs.
2	3	8.1	Gi
	9	8.8	L
	10	8.6	Ba
	11	8.5	G
	12	8.2	Hu
	13	8.8	L
	14	8.1	Ba
	24	8.2	Hu
	28	8.2	Ba
	28	9.1	G
3	5	8.4	O
	5	8.5	Ba
	9	9.0	O

090425
W Cancri

Mo.	Day	Est.	Obs.
2	10	11.7	S

093178
Y Draconis

Mo.	Day	Est.	Obs.
3	5	13.4	Y

093934
R Leo. Min.

Mo.	Day	Est.	Obs.
2	9	7.4	G
	12	7.0	Hu
	15	7.5	G
	24	7.8	G
	24	7.9	Hu
	25	8.4	S
3	2	8.0	G
	4	8.1	G
	5	8.5	O
	8	8.7	O

094211
R Leonis

Mo.	Day	Est.	Obs.
2	3	8.5	Gi
	7	8.4	Le
	8	8.1	Ha
	8	8.6	C
	8	8.7	Le
	9	8.7	Le
	9	8.5	G
	9	8.3	L
	10	8.4	B
	11	8.5	Le
	12	8.6	Le
	12	7.5	B
	13	8.2	L
	13	8.3	Ma
	14	7.0	B
	14	7.4	Le
	14	8.0	Ma
	14	7.8	G
	15	7.6	Gi
	15	8.1	L
	16	7.6	Ma
	23	6.6	L
	23	7.0	O
	24	6.7	L
	24	7.0	Ha
	24	6.5	Ba
	24	7.8	G
	25	6.6	B
	25	6.6	S
	25	7.4	Y
	26	7.4	G
3	1	7.1	Ma
	2	6.6	G
	3	6.5	Ba
	3	6.5	B
	4	6.8	Le
	4	6.5	G
	5	6.6	O
	5	6.5	Ba
	6	6.7	Le
	8	6.6	O

VARIABLE STAR OBSERVATIONS Feb.–Mar., 1913.—Continued.

103212
U Hydrae

Mo.	Day	Est.	Obs.
2	1	5.5	G

103769
R Urs. Maj.

2	24	12.8	B
3	5	12.9	B

105517
R Crateris

2	1	8.6	G
	14	8.4	G
3	4	9.0	G

122001
SS Virginis

2	15	6.5	G
3	4	6.7	G

122532
T Can. Ven.

2	13	10.0	Y
	25	9.9	Y

123160
T Urs. Maj.

2	1	9.0	G
	6	10.0	Ma
	7	9.7	Le
	8	10.1	Le
	8	10.0	Ba
	8	10.2	Ma
	9	9.6	G
	9	10.1	Le
	10	10.1	Ba
	10	10.0	L
	11	10.2	Le
	12	10.0	B
	14	10.6	M
	14	10.2	Ba
	14	10.1	Le
	18	10.3	Ba
	24	10.2	G
	24	10.3	S
	24	10.9	B
	24	10.9	Ba
	24	10.5	Y
	25	11.0	M
	25	11.0	Ba
	28	11 0	Ba
3	3	11.2	Ba
	4	10.2	Le
	5	11.9	B
	5	11.4	Ba
	6	10.8	Le

123307
R Virginis

2	16	8.9	G

123961
S Urs. Maj.

Mo.	Day	Est.	Obs.
2	1	7.4	G
	3	8.2	Gi
	6	8.0	Ma
	7	8.4	Le
	8	8.0	Ma
	8	8.0	Le
	8	8.3	Ba
	8	7.7	Ha
	9	7.5	G
	9	8.1	Le
	10	8.4	Ba
	10	8.5	L
	11	7.5	G
	11	8.3	Le
	12	8.0	F
	12	7.8	B
	12	8.1	Ma
	12	8.1	Le
	12	8.3	Ma
	13	8.5	L
	14	8.7	M
	14	8.3	Ma
	14	8.4	Ba
	14	8.4	Le
	15	8.3	Gi
	15	8.4	L
	15	7.5	G
	16	7.9	Ha
	16	8.2	L
	18	8.4	Ba
	18	7.5	G
	22	9.0	J
	23	8.6	L
	23	8.8	O
	24	8.8	Ha
	24	8.3	G
	24	7.9	B
	24	8.6	Y
	24	8.5	Ba
	24	8.8	S
	25	8.8	M
	25	8.5	Ba
	26	8.5	G
	28	8.7	Ba
	28	8.8	F
	28	8.5	G
3	1	8.8	Ma
	2	9.1	J
	2	9.2	M
	2	9.0	Ha
	3	9.0	Ba
	4	9.0	Le
	5	9.3	O
	5	9.3	M
	5	8.7	B
	5	8.8	Ba
	6	9.2	Le
	6	9.2	J
	8	9.2	J

S Urs. Maj.

Mo.	Day	Est.	Obs.
3	8	9.2	O
	9	9.4	O

124606
U Virginis

2	16	11.0	G
	25	11.6	Ba
3	5	11.5	Ba

132422
R Hydrae

2	1	4.0	F
	2	4.0	G
	3	4.7	Gi
	7	4.6	Gi
	9	4.5	L
	11	4.5	L
	12	4.2	G
	12	4.4	C
	13	4.4	L
	14	4.3	G
	15	4.6	Gi
	15	4.6	L
	18	4.3	G
3	4	4.8	G

132706
S Virginis

2	9	8.4	L
	13	8.5	L
	15	8.4	L

134440
R Can. Ven.

2	10	11.7	L
	10	12.0	Ba
	24	10.3	B
	25	10.6	M
	25	11.5	Ba
	28	9.9	Ba
3	2	10.4	M
	5	9.8	Ba
	5	10.3	M
	5	9.5	B

141567
U Urs. Min.

2	14	9.1	Ba
	18	9.0	Ba
	22	9.2	J
	24	8.5	S
3	2	8.9	J
	5	8.6	Ba
	6	9.2	J
	6	8.9	J

141954
S Boötis

2	25	12.8	Ba
3	2	12.3	J

142539
V Boötis

Mo.	Day	Est.	Obs.
2	3	7.8	Gi
	10	8.3	L
	14	8.4	F
	15	8.1	Gi
	15	8.3	G
	23	8.7	L

142584
R Camelop.

2	9	11.2	L
	15	11.4	L
	24	11.0	B
3	5	11.0	O
	5	10.9	B

143227
R Boötis

2	9	12.0	Gi
	13	11.0	L
	16	10.3	G

150605
Y Librae

2	9	9.2	L
	13	9.0	L
	15	9.0	L

151731
S Cor. Bor.

2	13	7.9	L
	15	7.6	G
	25	7.5	Ba
	28	7.5	Ba
3	4	7.6	G
	5	7.7	Ba

152714
RU Librae

2	18	9.5	G

153215
W Librae

2	15	11.5	L

153378
S Urs. Min.

2	9	10.7	L
	11	10.6	G

154640
V Cor. Bor.

2	15	8.0	G
	16	8.0	G
3	4	8.0	G

154428
R Cor. Bor.

2	1	5.7	G
	9	6.0	L
	9	6.3	Gi
	11	6.0	L

R Cor. Bor.

Mo.	Day	Est.	Obs.
2	12	5.4	C
	13	5.7	G
	13	6.0	L
	14	6.0	F
	15	6.1	Gi
	15	6.0	L
	16	6.0	G
	25	5.9	Ba
	28	6.0	Ba
3	3	6.1	J
	4	5.8	G
	5	6.1	Ba
	6	6.0	J
	7	6.0	J

154536
X Cor. Bor.

3	3	9.4	J
	7	9.3	J

154615
R Serpentis

2	14	10.5	G
3	5	10.9	Ba

154736
R Lupi

3	4	9.6	G

155823
RZ Scorpii

2	13	9.2	G

155847
X Herculis

2	11	5.9	L

162119
U Herculis

2	14	8.3	F
	14	7.3	G
3	4	7.3	G
	5	8.0	Ba

163172
R Urs. Min.

2	10	8.9	B
	24	9.5	B
	25	10.1	Ba
3	5	9.8	Ba

163266
R Draconis

2	9	11.0	L
	12	11.5	B
	25	11.9	B
	25	11.5	Y
3	4	11.4	Y
	5	11.9	B

VARIABLE STAR OBSERVATIONS Feb.–Mar., 1913.—Continued.

164715
S Herculis

Mo	Day	Est.	Obs.
3	3	10.0	J

165030
RR Scorpii

Mo	Day	Est.	Obs.
2	14	11.0	G
	18	10.7	G

170215
R Ophiuchi

Mo	Day	Est.	Obs.
2	1	8.8	G
	11	9.2	L
	13	9.3	L
	14	8.8	G
	15	9.3	L
3	3	10.5	J
	4	9.2	G

180531
T Herculis

Mo	Day	Est.	Obs.
2	14	10.8	F
	14	11.2	G

181136
W Lyrae

Mo	Day	Est.	Obs.
2	1	10.7	G

184205
R Scuti

Mo	Day	Est.	Obs.
2	9	5.9	L
	11	6.0	L
	13	6.0	L
	15	6.0	L
3	4	4.8	G

191350
TZ Cygni

Mo	Day	Est.	Obs.
2	11	10.9	L

193449
R Cygni

Mo	Day	Est.	Obs.
2	3	7.9	Gi
	9	8.4	L
	9	7.8	Gi
	11	8.4	L
	13	8.0	G
	13	8.4	L
	14	8.4	M

R Cygni

Mo	Day	Est.	Obs.
	14	8.5	F
	15	8.0	L
	16	8.0	G
	18	7.8	G
3	4	7.5	G

194048
RT Cygni

Mo	Day	Est.	Obs.
2	3	8.1	Gi
	9	6.9	L
	9	7.3	Gi
	11	6.9	L
	13	6.8	L
	14	7.0	F
	14	7.6	M
	15	7.0	Gi
	15	6.7	L
	16	6.7	G
	18	6.7	G
3	4	6.7	G

194348
TU Cygni

Mo	Day	Est.	Obs.
2	14	11.3	F

200647
SV Cygni

Mo	Day	Est.	Obs.
2	13	8.5	G
	14	9.2	F

200938
RS Cygni

Mo	Day	Est.	Obs.
2	3	7.5	Gi
	13	7.1	G
	14	8.0	F
3	4	7.5	G

201008
R Delphini

Mo	Day	Est.	Obs.
3	3	8.4	J

201647
U Cygni

Mo	Day	Est.	Obs.
2	1	9.6	G
	3	8.5	Gi
	9	9.8	L

U Cygni

Mo	Day	Est.	Obs.
	13	8.4	G
	14	9.2	F
	15	9.6	L
3	3	9.6	J
	4	8.4	G

202539
RW Cygni

Mo	Day	Est.	Obs.
2	13	9.5	G

202946
SZ Cygni

Mo	Day	Est.	Obs.
2	1	9.3	F
	1	9.3	G
	6	9.5	G
	12	8.9	B
	13	8.9	G
	14	9.5	F

204834
Y Cygni

Mo	Day	Est.	Obs.
2	1	7.1	G

210382
X Cephei

Mo	Day	Est.	Obs.
2	25	12.0	Y
3	5	12.5	Y

210868
T Cephei

Mo	Day	Est.	Obs.
2	3	9.4	Gi
	3	10.0	G
	8	9.9	Ma
	9	9.6	L
	10	9.2	B
	14	9.8	Ba
	15	9.6	Gi
	15	9.3	B
	15	9.6	L
	23	10.0	J
	24	9.6	S
	25	9.6	B
	25	10.0	Ba
3	2	9.9	J
	5	10.0	Ba
	5	9.5	B
	6	9.8	J

213244
W Cygni

Mo	Day	Est.	Obs.
2	3	5.5	L
	9	5.4	L
	9	6.3	G
	10	5.5	L
	13	5.4	L
	15	5.5	L

213678
S Cephei

Mo	Day	Est.	Obs.
2	10	9.3	B
	14	10.0	Ba
	24	10.8	J
	24	10.6	S
	25	9.6	Ba
	25	8.8	B
3	2	10.8	J
	5	9.0	B
	5	9.7	Ba
	6	11.0	J

213753
RU Cygni

Mo	Day	Est.	Obs.
2	1	8.3	F
	4	8.4	F
	9	8.9	G
	12	8.5	F

213843
SS Cygni

Mo	Day	Est.	Obs.
2	1	9.5	F
	3	8.8	L
	3	9.1	Gi
	4	8.4	F
	6	8.5	G
	9	9.2	L
	9	9.4	Gi
	9	9.9	G
	10	9.6	L
	10	10.4	G
	10	10.5	J
	11	10.9	L
	13	11.6	Y
	13	11.8	J
3	3	11.7	J

213937
RV Cygni

Mo	Day	Est.	Obs.
2	1	7.2	F
	1	7.1	G
	4	6.8	F
	9	7.0	O
	12	7.2	F
3	3	7.8	J

222439
S Lacertae

Mo	Day	Est.	Obs.
2	13	8.6	Y
	24	9.0	Y

230759
V Cassiop.

Mo	Day	Est.	Obs.
2	24	10.1	J
	24	10.2	V
	28	9.8	F
3	2	9.7	J
	6	9.5	J

233335
ST Androm.

Mo	Day	Est.	Obs.
2	10	9.3	B
	24	9.7	B

235182
V Cephei

Mo	Day	Est.	Obs.
2	16	7.1	G
	25	6.7	G
3	4	6.6	G

235939
SV Androm.

Mo	Day	Est.	Obs.
2	8	8.6	Y
	9	8.6	G
	12	9.2	O
	13	8.7	Y
	24	9.5	Y

No. of observations, 790; No. of stars observed, 121; No. of observers, 16.

Members of the Association are again urged to send in their lists promptly each month, so that they will be sure to reach the secretary by the 7th or 8th inst. at the latest. If it happens that there is no list to send in, will members please notify the secretary in order that there may be no delay in forwarding the monthly report.

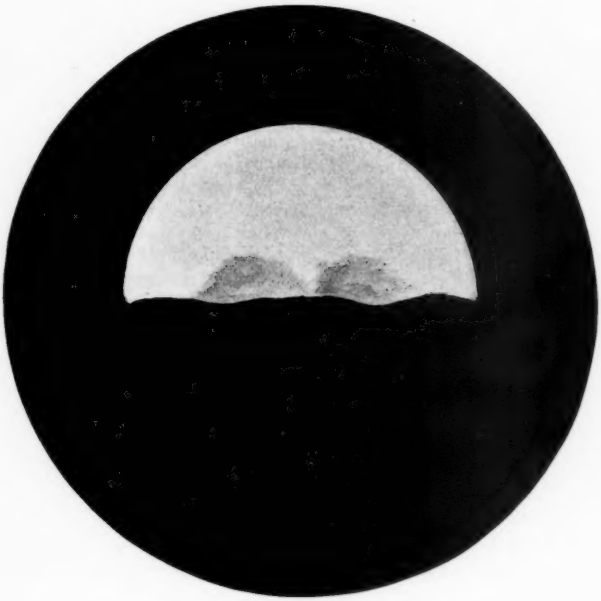
WM. TYLER OLCOTT
Corresponding Sec'y.

Norwich, Ct., Mar. 10, 1913.

The Planet Venus.—The beautiful planet Venus was at its maximum elongation on February 11 last, being at 46° 43′ east of the sun.

Now it is marching with retrograde motion and will be at inferior conjunction on April 24. Venus will have its greatest brightness on March 22, when its elongation will be 39° and its diameter will measure 41″. The distance from Venus to the earth on that date will be 0.42, taking as unit the distance from the sun to the earth (149,000,000 kilometers).

The brightness of Venus on March 22 may be represented by the number 63, that is to say, the planet will be 63 times as bright as *Alpha* Lyrae. Similar circumstances will occur on May 25; but then Venus will be morning star (*Lucifer*) and not evening star as it is now (*Vesper*).



THE PLANET VENUS
Observed by Professor Luis G. León on Saturday February 22, 1913, at 6^h 30^m p.m. with 80mm Zeiss refractor, eyepiece = 6 F.

Last evening (Saturday, February 22) at 6^h 30^m, I pointed my 80mm Zeiss telescope at the planet Venus. The elongation was 46°, the diameter 27″, the brightness 52, and the surface illuminated 0.46 (almost one half). The horns looked flat and not sharp as those of the moon. Besides, the northern horn looked flatter than the southern one, and both were poorly defined. The Venus terminator was undulated and not regular and there were very clearly seen two dark spots near the terminator. These spots, which probably correspond to very high mountains on Venus, were observed as early as 1700 by the French astronomer Lahire. The most interesting observations of these spots were made by Father Vico, of Rome, in 1841.

Sometimes the brightness of Venus is so great that the planet can be easily seen in full day, notwithstanding the light of the sun. When in the year 1794, General Bonaparte entered Paris, he noticed that the people looked at the sky and not at him. Bonaparte wanted to know what they were looking at, and found that the French were looking at Venus at midday.

Venus and Saturn will be at conjunction in the eastern sky on the morning of the 21st of July next.

LUIS G. LEÓN.

Coyoacán (near Mexico City), February, 1913.

GENERAL NOTES.

Professor B. Baillaud, director of the Paris Observatory, has been elected president, and Professor H. Deslandres, director of the Meudon Observatory, vice-president, of the Paris Bureau des Longitudes for 1913.

The Earl of Crawford died on January 31, at his London residence in the 66th year of his age. He was much interested in astronomy and had a splendidly equipped private observatory at Dunecht, Aberdeenshire, where several well-known astronomers carried out an extensive and valuable series of astronomical observations. In 1874 he organized an expedition to Mauritius for the purpose of observing the transit of Venus of that year, and of obtaining heliometer measures of Juno and neighboring stars, for determining the Solar parallax. He was president of the Royal Astronomical Society in 1878-80 and was elected Fellow of the Royal Society in 1878. In 1889 he dismantled the observatory at Dunecht and presented the instruments and library to the Royal Observatory at Edinburgh.

Professor C. H. Gingrich, associate editor of POPULAR ASTRONOMY, lectured before the Winnipeg Centre of the Royal Astronomical Society of Canada, on Friday evening March 7, on the subject "Modern Methods of Stellar Photometry."

Mr. Wm. B. Davis, of Ocean City, New Jersey, writes that he has just imported a Zeiss 3½-inch telescope, which is a fine instrument.

Dr. H. D. Curtis, the retiring president of the Astronomical Society of the Pacific, at the annual meeting on Jan. 25, 1913, gave an address on the subject "Our Stellar Universe," in the course of which he reviewed the life and work of the Bruce Medalist for the year. Publication No. 146 of the A. S. P. gives the address in full, illustrated with photographs of Professor Kapteyn and his Laboratory at Groningen.

The Bruce Medal of the Astronomical Society of the Pacific has been awarded for the year 1913 to Professor J. C. Kapteyn of Groningen, Holland, in recognition of his services to astronomy in the study of the proper motions of the stars.

Mr. Oliver J. Lee of the Yerkes Observatory has recently published in the *Astrophysical Journal* an investigation of The Spectroscopic System 9 Camelopardalis. This paper is in the form of a dissertation submitted to the Ogden Graduate School of the University of Chicago in partial fulfilment of the requirements for the degree of Doctor of Philosophy. The study here is chiefly of the calcium lines which are exceptionally strong and sharp in this star. From these lines the period is found to be 7.9957 days. The conclusion with respect to the masses of the components of the system is that the one component has 2.85 times the mass of the other, and that the combined mass is 0.0023 times that of the sun

---

Allegheny Observatory.—A pamphlet just issued (Miscellaneous Scientific Papers of the Allegheny Observatory—New Series, Vol. 2, No. 2) gives in full the addresses made at the dedication of the New Observatory August 28, 1912.

Detroit Observatory.—Publications of the Astronomical Observatory of the University of Michigan, Vol. 1, pages 1-72, recently issued, gives a very complete and interesting historical account of the Observatory, illustrated with fine cuts of the old and new buildings and the new apparatus which has recently been installed. A valuable account is given by Dr. Ralph H. Curtiss of the design and construction of the single-prism spectrograph which is used in connection with the 37½-inch reflecting telescope.

Smithsonian Pyrheliometry Revised.—In recent years the Smithsonian Institution, in order to promote accurate measurements of the solar radiation in other parts of the world with instruments whose indications are quite comparable, has sent out several copies of the Silver Disk Pyrheliometer. The number of these instruments which have been sent out has now reached about twenty.

In order to test these instruments and determine their constants, new forms of standard pyrheliometers have been devised, which will measure test quantities of heat within one percent. The most recent of these is called "Standard Water-stir Pyrheliometer No. 4". In this the solar radiation is received in a blackened chamber surrounded by a known quantity of water in a copper vessel. The water is vigorously stirred by a stirring device run by an electric motor. A platinum resistance thermometer, fully bathed by the water of the pyrheliometer, serves to determine the rise of temperature per minute of the known quantity of water.

More Evidence of a Cosmic Cloud of Calcium.—In *A.N.* 4633 Mr. Zaccheus Daniel, of the Allegheny Observatory, calls attention to the spectroscopic binary BD.—1°943, as one in which the K-line does not share in the oscillations of the other lines. The star is less than a degree from the spectroscopic binary δ Orionis, for which Hartmann in 1904 found the K-line to be stationary. Thirteen spectrograms have been obtained of this star with the Mellon spectrograph at Allegheny, and the measures of the best hydrogen and helium lines indicate a range in velocity of considerably more than 200 kilometers, with a period of about 3.05 days. The mean of the measures of the K-line is + 17km which is close to the velocity obtained by Hartmann for δ Orionis from the K-line, and so goes to confirm the supposition that this particular line is produced by absorption, not in the atmospheres of these stars, but in a calcium cloud lying between them and the solar system.

Stars of the Taurus Stream.—In *A.N.* 4633 Mr. Adolf Hnatek, of Wien, Austria, gives a list of thirty stars, in the first four hours of right ascension and in north declination, whose proper motions are directed approximately toward the convergent of the Taurus stream, discovered by the late Professor Boss. In order to make the proper motions of these stars consistent with that of the Taurus stream it is necessary to assume parallaxes which, in every case, place the stars more than twice as far away as the stars of the Hyades group.

What Becomes of the Light of the Stars?—"One of the most astounding things in nature," writes Professor Frank W. Very, in the Popular Science Monthly for March 1913, "is the enormous energy which the sun is continually dispensing as radiation to surrounding space. The earth, as viewed from the sun, is a mere point in space, and receives no more than 1/2,200,000,000 of the radiant energy which the sun is outpouring so lavishly. Yet out of this small fraction of the total radiation, practically all the terrestrial activities of wind and wave, tropical hurricanes and avalanches of ice on alpine slopes and the no less potent but milder forces which clothe the earth with verdure, originate.

"If we include all the planets in the solar system, and assess the outgoing solar rays at the maximum tariff imposed by the obstruction in their path, it still remains true that only 1/100,000,000 of their power is directly utilized in maintaining the thermal equilibrium and life of the attendant orbs, dependent from day to day for these gifts upon the dispenser of all of this bounty.

"The solar outpouring for even a single day is inconceivably great, yet the same flux of energy has been going on ceaselessly and with very little change in absolute intensity for at least a hundred million years, as the records of geologic time attest. If only one part of solar radiant energy in one hundred million is directly utilized, what becomes of the other ninety-nine million, nine hundred and ninety-nine thousand, nine hundred and ninety-nine? Remember, also, that our sun is but one among hundreds of millions of stars made known to us by our photographic telescopes, all outpouring similar torrents of energy, and the question comes home to us accentuated with many million-fold intensity."

Professor Very discusses the possibility of light being absorbed by meteoric or gaseous matter in space, and whether there may not be other stellar systems beyond our own whose light is lost because of such absorption. He studies the relations between the size and brightness of the thousands of white nebulæ which have been catalogued and finds that on the average the smaller nebulae are much fainter than the larger ones, whereas if they are smaller simply because of greater distance they ought to be equally bright on the average with the nearer nebulae, unless their light is absorbed by some intervening medium.

His conclusion is that "space contains myriads of galaxies which would make the midnight sky one blaze of light, were it not for the absorption of light by the ether of space. This absorption cannot be a selective scattering by gaseous molecules, because this would deplete the radiation of short wave-length unduly, and would redden the light of the more distant nebulæ, whereas no such change of color with distance is found. Neither can the absorption be due to the general absorption of radiation of every wave-length by coarser meteoric dust, since the meteoritic material would in time become heated to incandescence, as Arrhenius has noted, and in this case also the entire heavens must glow. There remains, then, the supposition that the ether itself absorbs the radiation from the stars, and that in this fixation of energy, matter originates."

Eclipse of a Star by One of Jupiter's Moons.—A very unusual piece of astronomical work, from a part of the world in which little has previously been done, deserves description this month. Though published in the German *Astronomische Nachrichten*, it originates in Chile, where Dr. Ristenpart, a German Astronomer of distinction, is in charge of the observatory at Santiago.

On the night of August 13, 1911, the third Satellite of Jupiter, Ganymede, passed directly in front of a star of the seventh magnitude, in the constellation Virgo, and for observers in the southern part of the earth, actually hid the star for more than four minutes.

The circumstances of this remarkable occultation were carefully calculated in advance by Banachiewicz, and it appeared that the best observing stations would be in South America. Dr. Ristenpart, with great energy, set about the organization of observers throughout Chile, and it is undoubtedly due to his zeal and forethought that the important results which we are to describe were obtained.

Why it was important to have observations made at as many places as possible appears from the fact that, since Ganymede is much smaller than the earth, its shadow, if we may so describe the region from which at any moment it conceals the star, is only a little more than 4,000 miles in diameter.

As Jupiter and its satellite moved, this "shadow" crossed the earth, its center passing over the southern extremity of South America, a little north of the straits of Magellan, while its northern limit reached barely to the boundary between Chile and Peru. Observers at southern stations would therefore see the satellite pass almost centrally over the star, while for those in northern Chile the latter would be concealed for a much shorter time behind the northern edge of Ganymede.

By comparison of the duration of the occultation, as seen from different places, it should therefore be possible to obtain very accurate information regarding the size and shape of the eclipsing body. In spite of unfavorable weather and other difficulties, the various observers—mostly school teachers or amateur astronomers—were able to obtain reliable observations at five stations, extending almost along the same meridian for 1,000 miles. Except at Santiago, the observers had only small telescopes of about four-inch aperture, with which the satellite could not be distinguished, as regards its appearance, from the star, except that it was a little brighter. The two came closer together until they could no longer be distinguished, but formed one mass of light. Then, suddenly, the light diminished to about one half, this being, of course, the real instant when the star vanished behind the satellite. After a time the light increased again as the star came out; and then the mass of light gradually separated into two points.

In addition to these visual observations, a number of photographs were obtained by Dr. Zurbellen, which defined very accurately the relative positions of the star and satellite before and after their conjnnction, and made it possible to calculate just how far apart they must have appeared at any time.

Working along these lines, Dr. Ristenpart finds that, in order to get a satisfactory agreement between theory and observation, it is necessary to assume that the satellite, like Jupiter itself, is flattened at the poles, for otherwise the calculated length of the occultation at the northernmost station, where the star appeared to pass just inside the satellite's disk, would be much longer than the observed time. As the rate of motion of the satellite is accurately known, the maximum length of the occultation affords a very precise measure of its diameter. Dr. Ristenpart finally concludes that the equatorial diameter of the satellite is 4,700 miles and the polar diameter 4,300, so that it is a little more flattened, in proportion to its size, than Jupiter himself. The diameter of the satellite was previously supposed, from micrometer measures, to be about 3,600 miles, and the difference between this and

the new value is surprisingly large; but owing to the method of observation, Dr. Ristenpart's results seem to be entitled to very serious consideration. The mass of this satellite is known, from its attraction on the other satellites, to be about 1/12,000 that of Jupiter, or a little more than 1/4 that of Mars. But, according to the results just given, it is a little larger than Mars. This would make its density less than 1/4 that of Mars, and actually less than that of water—intermediate between the densities of Jupiter and Saturn. Even with this low density, it must be in rapid rotation, with a period not more than ten or twelve hours, to account for the polar flattening.

It is perhaps most interesting of all to note that, according to the most definite of the observations, the disappearance of the star behind the satellite was almost instantaneous, the loss of light lasting only a second or so. This means that the apparent diameter of the star was not more than 1/300 that of the satellite; in other words, less than 1/500 of a second of arc. This is quite what is to be expected for a star of the seventh magnitude; but it is interesting to have the extreme smallness of the apparent diameter of a star confirmed by direct observation.

[Henry Norris Russell in *Scientific American*, March 1, 1913.]

Computer Wanted at the U. S. Naval Observatory.—The following notice is given place here at the request of Captain J. L. Jayne, U. S. N., Superintendent of the Naval Observatory:

No. 195 UNITED STATES CIVIL-SERVICE EXAMINATION.

COMPUTER (MALE).

NAVAL OBSERVATORY.

April 9-10, 1913.

The United States Civil Service Commission invites attention to the examination to be held for computer in the Naval Observatory, for men only, on April 9-10, 1913. From the register of eligibles resulting from this examination certification will be made to fill a vacancy in the position of miscellaneous computer, in the Naval Observatory, Bureau of Navigation, Navy Department, and vacancies requiring similar qualifications as they may occur in that Observatory and the Nautical Almanac Office. The Department states that miscellaneous computers are paid by the hour and earn from $1,000 to $1,200 a year. Promotions are made from this grade, without further examination, to the grade of assistant, at $1,200 a year, as vacancies occur.

The scope and character of and requirements for this examination, and the list of places at which it will be held, are contained in Manual of Examinations for the Spring of 1913.

Persons who desire this examination should at once apply for the Manual of Examinations and Form 1312 to the United States Civil Service Commission, Washington, D. C., or to the Secretary of the Board of Examiners, Post Office, Boston, Mass., Philadelphia, Pa., Atlanta, Ga., Cincinnati, Ohio, Chicago, Ill., St. Paul, Minn., Seattle, Wash., San Francisco, Cal., Customhouse, New York, N.Y., New Orleans, La. or Old Customhouse, St. Louis, Mo. No application will be accepted unless properly executed and filed with the Commission at Washington. In applying for this examination the exact title as given at the head of this announcement should be used.

As examination papers are shipped direct from the Commission to the places of examination, it is necessary that applications be received in ample time to arrange for the examination desired at the place indicated by the applicant. The Commission will arrange to examine any applicant whose application is received in time to permit the shipment of the necessary papers.

Issued February 19, 1913.